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A CENTENNIAL SURVEY OF AMERICAN FLOODS

Fifteen Significant Events in the United States, 1890-1990

David T. Smith
David B. Reed

National Weather Service
Hydrologic Services Division
Fort Worth, Texas

Scientific Services Division
Southern Region
Fort Worth, Texas
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UNITED STATES DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

National Oceanic and Atmospheric Administration
John A. Knauss
Under Secretary and Administrator

National Weather Service
Elbert W. Friday
Assistant Administrator

FOREWORD

The civilian weather services of this nation now span a full century, 1890-1990. Any history of 100 years of civilian weather services would not be complete without a considerable amount of river services history. And any history of river services provided by the civilian service would be incomplete without a discussion of great floods of that 100-year period.

River data began to be collected in an organized fashion under the Army's Signal Corps Service as early as 1873, largely in support of navigation on some of the Nation's major eastern rivers. It soon became clear, however, that the single most intriguing, most bothersome, and most awesome aspect of the Nation's river flows was the repeated rise of those rivers, of every ilk, to flood.

The early eastern frontier had no developed history from which any reliable understanding of flood frequency and severity could be fathomed. And as the settlements pushed westward into an increasingly arid climate, it may even have been believed that the newly settled regions, away from the humid eastern half of the continent, would be entirely free from floods. An ominous note may have been provided, however, by the journals of pioneers and frontiersmen rife with accounts of wild rivers in flood, and of the perils and problems they caused as the frontier was pushed ever westward by the new continent's burgeoning and bustling, adventuresome population.

Meanwhile, towns earlier established on major river courses in the east began through the years to experience the recurring agony of repeated floodings as the seasons wore on. As the cities and towns were established, slowly but certainly two major facts about the natural hydrology of the fledgling Nation became manifest. First, floods' severity seemed to have no bounds. They would occur in bewildering sequences of magnitude and an "unbelievably great flood" of one year would be discouragingly exceeded in magnitude by some later disastrous inundation. Second, no region of the Nation, finally from coast to coast and border to border, seemed truly safe from at least an occasional submersion. Indeed, floods were finally recognized as an endemic experience of the American terrain, natural events whose consequences ultimately would affect the lives of every individual in one way or another throughout the great American landscape.

In exceedingly general terms, the history of the past century of floods in the United States may be broken into three eras. In the first, earliest period, floods were simply experienced in an unannounced, uncontrolled fashion, sometimes wreaking tremendous havoc. Through human experiences, as much as by observation and documentation, these floods began to reveal their true nature, spatially and temporally, and their potential for various degrees of destruction.

Once these aspects of floods were fairly well understood, a second era of attempting to control and regulate their occurrence through the means primarily of great dams and levees and other control measures began. This era, beginning in the twentieth century, was given considerable impetus by the great economic depression of the 1930s when federal works programs were planned to provide an economic stimulus to the Nation.

Following construction of many control measures, which proved partially successful but at great national financial cost, came the third era around the close of the decade of the 1950s. Here a mixture of controls, warnings, and structural accommodation heralded the Nation's maturity, finally, in realizing that, to a certain extent, these flood occurrences would need to be accommodated more than totally controlled, or much less prevented.

Through the century, through the various learning phases of the Nation as it grappled (and grapples) with its flood problems, the civilian weather service has been an active partner with the public -- learning with it, growing in understanding, and providing to the nation to the best of its abilities the flood warning services required by an active, vigorous, and demanding public.

It is unlikely any distinct fourth era lies beyond. Modern surveillance methods and an increased understanding of the atmospheric processes which bring the surfeits of precipitation that key great floods may ultimately enable us to provide greater warning services to the nation; it is unlikely, however, that floods will be totally prevented. It is neither financially nor technically feasible. A mixture of high-tech vigilance and structural control measures is our best hope. With this hope, the civilian Weather Service stands in its midst, an agency whose second century will continue to be woven tightly into the fabric of flood experience across the Nation, as has been its first century of service.

There was no precise set of criteria used to select the floods chosen for documentation in this study. Still, the selected floods have some common characteristics. All were extreme events, unforgettable to those who experienced them first-hand. All were significant to some degree, all wreaking great damage. Most were of an overwhelming magnitude, either in scope of area affected or in scale of severity, or in combination. Many served as initiating agents of reform, spurring flood control acts and other sorts of legislation, promoting the establishment of new agencies, or forcing the alteration of public viewpoints about floods, their characteristics, their frequency, and their potential for destruction. Some inflicted great loss of life; all inflicted a great deal of suffering upon their victims. It is not stretching truth to say that to a large extent we are where we are today in flood protection because of the costly lessons these floods taught us.

One may wonder why the now nearly-fabled Johnstown (Pennsylvania) flood is absent from the pantheon of inundations presented in the following study. It surely exhibited most of the general characteristics mentioned above. In point of fact, however, the Johnstown flood occurred May 31, 1889, a year-and-a-half prior to the formation of the Nation's civilian Weather Service, and hence fails to meet the one firm criterion established for this study -- namely that the floods occurred during the first century of the civilian Service's existence (1890-1990).

Finally, the floods that have taught us these great lessons are not all included in this brief presentation. There is ample opportunity remaining for anyone interested to conduct their own studies and research into the many great flood events which contribute to this Nation's rich hydrologic history.

Fort Worth, Texas
October 1990

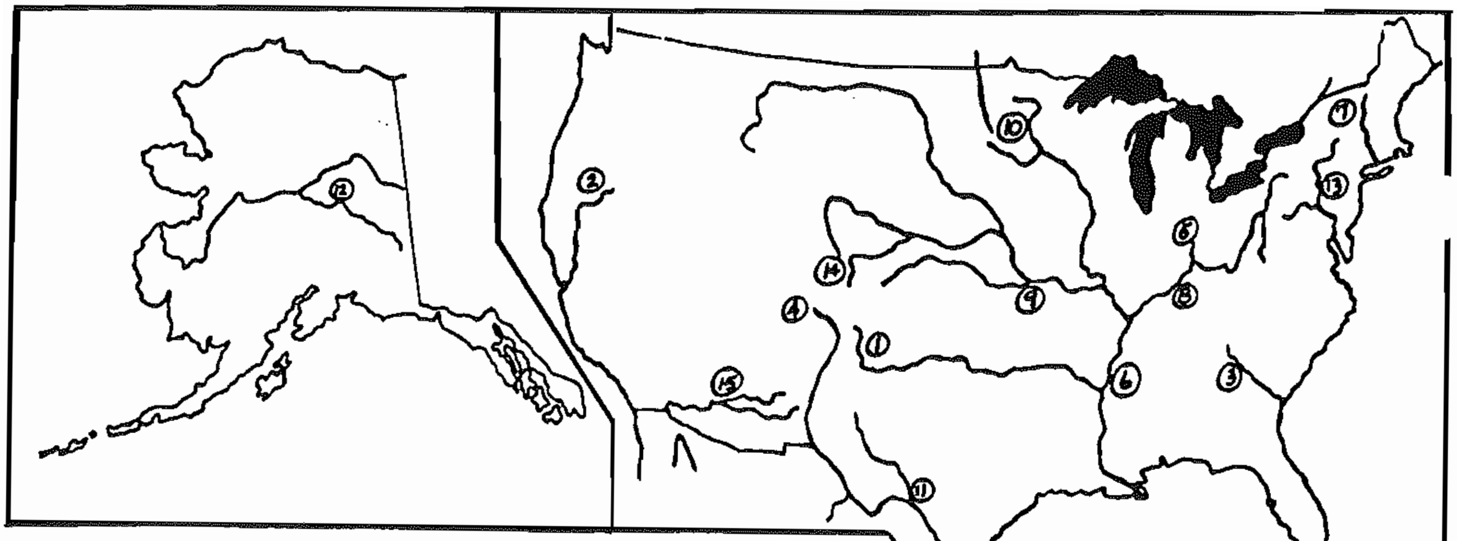
Thanks are due...

...to the many energetic National Weather Service individuals actively involved in the Centennial celebration activities of our Civilian Weather Services. Their enthusiasm has provided a favorable climate for the conception and development of many projects, of which our historical study here is but one.

...to the Chief of Southern Region's Scientific Services Division, Mr. Dan Smith, for both his encouragement of the study and the time he willingly spent diligently reviewing the draft. He provided numerous worthwhile suggestions for the study's improvement.

...to Ms. Marsha Spencer, Southern Region Headquarter's secretary to Scientific and Hydrologic Services Divisions, for having efficiently created an attractive, readable product out of the disorder of our original drafts.

SRH-HSD



1. 1904 King Gillette granted U.S. patent for disposable razor.
September rains drench New Mexico Territory.

2. 1907 Oklahoma Territory admitted as Union's 46th state.
Winter rains climax in March flood in Northern California.

3. 1908 Henry Ford introduces the Model-T car.
Tropical storm deluge floods Augusta, Georgia.

4. 1911 President William Howard Taft dispatches 20,000 U.S. troops to Mexican border.
Eight-inch mountain rain produces record Rio Grande flood.

5. 1913 Sixteenth Amendment grants Congress power to tax.
March flood taxes Dayton, Ohio, to the limit.

6. 1927 Charles Lindbergh pilots the *Spirit of St. Louis* across the Atlantic.
Massive rains swamp Middle Mississippi Valley.

7. 1936 Jesse Owens performs stunningly at Berlin's Summer Olympics.
Northeast U.S. floods register on Maine's "Freshet Oak."

8. 1937 Aviatrix-feminist Amelia Earhart tracelessly vanishes over Pacific attempting global air-circuit.
Astounding January rainfall sends entire Ohio River Valley into unprecedented flood.

9. 1951 TV's *I Love Lucy* premiers.
Friday, July 13 -- The single "greatest day of flood destruction" in the Midwestern U.S.

10. 1952 *High Noon* signifies more than lunch-time to Gary Cooper.
Spring thaw causes snowmelt flood over Upper Midwest.

11. 1954 U.S. Supreme Court rules public school segregation violates 14th Amendment.
Hurricane Alice violates U.S.-Mexican border.

12. 1967 *Bonnie and Clyde* screen epic replays bank heists of errant couple.
Fairbanks, Alaska, suffers Chena River August rampage.

13. 1972 Watergate's scandal saturates the Nation's consciousness.
Hurricane Agnes saturates the Susquehanna and surroundings.

14. 1976 U.S. celebrates second Centennial.
Big Thompson Canyon flood spoils Colorado's first Centennial.

15. 1978 President Jimmy Carter mediates signing of Camp David Accords.
Southwestern states unusually wintry, with Gila-Salt River flood.

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NEW MEXICO'S CANADIAN RIVER FLOOD OF SEPTEMBER-OCTOBER 1904

THE CANADIAN RIVER

The 875-mile-long Canadian River, a major tributary of the Arkansas River, joins that primary stream in the relative lowlands of east-central Oklahoma, but has its source in the 8,000 to 13,000-foot-high Alpine Mountains and rolling foothills of northeastern New Mexico. These spectacular mountains, named the Sangre de Cristos by the colonial Spanish settlers of the seventeenth century, the first Europeans to see the region, provide a picturesque setting for the Canadian's source, a region of cragged peaks, narrow-cut canyons, and alpine meadows. The emerging mountain rapids feed and merge into meadow streams and finally form rivers in the high plain of northeastern New Mexico below the Sangre de Cristo's foothills.

Flowing eastward, leaving the arid eastern New Mexico plateau, the Canadian sharply cuts through the semi-arid Texas panhandle plains, emerging finally as a sluggish river, often nearly dry, through its Oklahoma run. Most upper valley flow is developed from the annual melting of springtime snowpacks from the high mountains. The spring "flood" is predictable -- generally an event drawing bemused appreciation from the upper valley's largely rural populace. By early summer, the Canadian's flow is usually spent, commencing a dormancy normally to be awakened only by the following year's melt season.

During some years, however, the pastoral rhythm of the Canadian is disrupted by unusually heavy late-summer early-autumn rains which can quickly turn the normally pleasant mountain and meadow stream system into a frenzied network of hissing jetways capable of destroying anything within their paths. The reigning granddaddy of such freshets was the September-October 1904 flood on the Canadian, a flood which exceeded all known historical floods, and has yet to be duplicated to this day.

THE RAINS OF SEPTEMBER 1904

There is no question as to the primary cause of the 1904 flood. Unusually heavy rainfalls commenced throughout most of New Mexico September 26, clipping southeastern Colorado and far west Texas as well. The rainfalls were abnormal for their prolongation and amount over the normally arid region. Up to five successive days of significant rainfall left the entire state of New Mexico reeling in floods, as well as extreme southeast Colorado and the middle Rio Grande of far west Texas. Nowhere, however, in the approximately 150,000-square-miles affected by the rains, was flooding as severe as it was in the Upper Canadian Valley. It was exactly over the 8,000-square-mile uppermost drainage of the Canadian that the rains became centered, with storm totals for the five days exceeding seven inches in the Canadian's headwater mountain streams. About 80% of the rain fell in a 36-hour period September 28-29; and these rains sent all the tributaries into immediate overflows, unlike anything ever seen in the area before. The results were catastrophic, enduring, and unforgettable to those who witnessed the scenes of tumultuous destruction wrought by searing mountain streams gone wild. Rainfall Table A is a ledger of rainfall over the entire state of New Mexico for the period September 26-30, 1904, exclusive of the Canadian drainage. Rainfall Table B, for the same time period, shows rainfalls gaged over the Canadian drainage.

There seems to be no established evidence to suggest a tropical storm origin for these September rains. Walter Smith's study of *Eastern Pacific Tropical Storms* (4) does not show a 1904 event, nor does George Cry's (5). This Canadian River flood is in distinct contrast to the colossal rains of October 1911, clearly caused by a tropical storm, that touched off the Upper Rio Grande flood of that date, just 150 miles west of the Canadian River's 1904 flood source region.

THE FLOOD

Ultimately the floodwaters, though developed only in the uppermost New Mexico drainages, would affect the full length of the Canadian to its junction with the Arkansas River in east central Oklahoma. Nowhere, however, was the flood as awesome, spectacular, and destructive as it was in its source region. Perhaps the single most damaged community was Watrous, New Mexico, located immediately upstream of the junction of the Mora River and Sapello Creek, where eight lives were lost. Read an eye-witness account found in the *Monthly Weather Review* (2):

> *Both streams (Mora and Sapello) were raging currents. As they came together at an angle of about 45°, the waters were hurled high into the air with a roar almost like Niagara, the two streams forming a veritable maelstrom as the monster currents struggled for mastery. Swirling and tossing on the crest of the flood were heavy timbers, great cottonwood and pine trees, and fragments of roofs, fences, and corrals. It was a terrible and awe-inspiring sight. Just below the juncture of the streams they were hurled against the Santa Fe tracks, obliterating them as far as one could see. Half a mile down the valley stood the great steel bridge lately constructed. The big structure towered like a monarch above the floods, with the approaches on both sides gone, but supported by the two massive stone abutments. For a moment beneath and on both sides the flood rushed on its mad course of destruction, soon carrying the bridge and everything in its path.*
>
> *On the terrible Thursday morning those who looked from the heights above Watrous gazed over five miles of wild, raging sea which threw columns of spray high into the air and whose roaring would have silenced the sound of the most violent tempest on the iron bound shores of the Bay of Fundy. Past all imagination, conception, or belief, say those who witnessed the spectacle, was the fury of the flood at the confluences of the Mora and Sapello Rivers.*

Numerous mountain hamlets suffered greatly from the flood, and farming and orchard lands withstood frightful losses. Many houses were carried away; and an unknown number of people, but measured in dozens, lost their lives.

The greatest single orchard loss was that of one near Springer, New Mexico. Ten thousand peach trees, 2000 apricot, 2000 almond, and 3000 cherry, plum and other trees were swept away. Other native trees, some estimated to have been 2000 years old, were carried away in raging torrents.

A great number of railroad tracks and bridges were lost. These bridges exacerbated the flooding by acting as partial dams which built temporarily super-elevated flood pools behind the bridge-dams until finally the structures were torn away by the elevated pressures and currents. Near Logan, New Mexico, where the flood wave crest discharge was finally estimated to have been 278,000 cubic feet per second (probably the maximum for the entire Canadian River reach during this flood), perhaps the most spectacular bridge failure occurred (1). The Rock Island Railroad's bridge there was one of the highest in the U.S. West, soaring 135 feet above the Canadian's low water level. It was a steel bridge, thought capable of withstanding almost anything; but 200 feet of bridge was torn away when pent-up flood waters furiously topped the structure and breached the bridge. Elsewhere, upstream in the Mora River's canyon, an entire train track was lifted out of the narrow canyon and hurled two miles downstream. Engineers claimed they could not explain the water's feat in this instance.

Downstream of Logan the weather had remained dry and hot during late September. As a consequence, residents along the lower river were surprised to see their normally inactive autumn riverbed begin to spring to life by October 1. The rise was slow, at first, but steady, as the great flood wave resolutely surged downstream. At its height across Oklahoma, the flood renewed its visit of misery.

Again, a quote from the *Monthly Weather Review* (2) paints the picture:

> *The flood of the South Canadian River (Oklahoma) of October 1 to 4, 1904, will stand memorable as the most destructive one in the history of this section since its settlement.... The feeble stream, winding its way in a shallow bed, became a vast flood that rolled a wall of water eighteen to twenty feet deep, in places spreading from hill to hill, with width varying from one to two miles, sweeping everything from its path and covering the valley with sand from one-half to four feet in depth, completely obliterating everything in the form of vegetation.*
>
> *The force of the water was so tremendous that nothing could stand in its course; crops, bridges -- both iron and wooden -- trees, and houses were swept away like straws and swallowed up in the sands. The roar of the water was heard for miles on either side, like that of the sea.*

FLOOD EPILOGUE

The magnitude of this 1904 flood on the Canadian River was such that it stands as a singular event even to this day for the upper basin. Old settlers in 1904 spoke of an earlier large flood in 1885, one that had no equal for decades prior to that. An estimate of maximum discharge for the 1885 flood at Logan, New Mexico, on the Canadian was placed at 70,000 CFS, or roughly only one-fourth that of the 1904 floods' peak discharge of 278,000 CFS. And further, in terms of total volume of flow, the 1904 flood has been judged to have been significantly more than quadruple the 1885 flood. Five years after the 1904 inundation, the Upper Canadian flooded again (3); but like the 1885 flood, it nowhere approached the magnitude, duration, nor destructive bent of the flood under study. The September 6, 1909, flood at Logan, New Mexico, was believed to have crested at 8 to 10 feet less stage than the 1904 flood, and at a discharge of about 141,000 CFS. This flood was also of shorter duration; and it is believed the causative rains were not as great nor as general over the upper basin, averaging only about 2.50 inches over a three-day span, September 3, 4, and 5.

Within the United States at the turn of the twentieth century, the Upper Canadian basin was a remote, sparsely populated region, one where, because of its mostly semi-arid climate, floods were not considered to be threatening, nor even likely, occurrences. As a consequence, this huge and totally devastating flood became a loud voice in a chorus of late-nineteenth and early-twentieth century floods which sent a clear message to the nation. No portion of the nation's continent was safe from flood devastation, regardless of climate and location. H. C. Frankenfield may be quoted from the *Monthly Weather Review* (2) expressing this view:

> *Those (1904 floods) in New Mexico and southeastern Colorado were probably unprecedented, both as to volume of water and extent of territory affected, and their effect upon future engineering problems will doubtless be most pronounced.... Among the lessons of these floods is the suggestion that the River and Flood Service of the Weather Bureau may be extended in these regions with at least a fair degree of utility. Two officials of the Bureau are now on the ground, examining the flooded districts with this end in view.*

REFERENCES

1. United States Geological Survey, Water Supply and Irrigation Paper No. 147; *Destructive Floods in the United States in 1904*; Edward Charles Murphy and others; 1905; pages 120-130.

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3. *Engineering Record*, "Flood Data in Canadian River Basin, New Mexico; December 21, 1912," page 695.

4. NOAA Technical Memorandum NWS WR-197, *The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States*, Walter Smith, Department of Atmospheric Sciences, University of Arizona, Tucson, Arizona; August 1986.

5. *Tropical Cyclones of the North Atlantic Ocean, 1871-1986*, U.S. Department of Commerce, NOAA, NWS, NESDIS, Historical Climatology Series 6-2.

NEW MEXICO PRECIPITATION SEPTEMBER 1904
(Exclusive of Canadian Basin)

STATION	26th	27th	28th	29th	30th	Total
Alamogordo	-	0.80	0.55	0.75	-	2.10
Albuquerque	T	-	-	0.86	-	0.86
Arabela	T	0.08	0.51	2.70	1.88	5.17
Cambray	-	-	1.25	0.80	-	2.05
Carlsbad	-	-	-	0.95	-	0.95
Cloudcroft	0.10	2.80	1.40	0.90	-	5.20
Deming	0.16	-	1.20	1.10	-	2.46
Eagle Rock Ranch	0.90	0.19	*	2.30	3.61	7.00
Elk	-	-	-	3.43	0.38	3.81
Engle	-	4.20	1.00	-	-	5.20
Fort Bayard	T	-	0.74	0.56	-	1.30
Fort Stanton	T	-	1.00	2.00	2.86	5.86
Hillsboro	0.09	-	*	3.25	-	3.34
Las Vegas	0.05	0.10	0.26	2.87	1.77	5.05
Los Lunas	-	-	-	1.85	-	1.85
Mesilla Park	T	T	1.63	-	-	1.63
Mountainair	T	-	0.25	1.56	0.10	1.91
Roswell	-	-	0.42	0.75	-	1.17
San Marcial	-	-	-	2.00	-	2.00
Santa Fe	0.17	0.33	-	1.08	1.43	2.81
Socorro	0.21	-	-	3.61	-	3.82
Strauss	-	-	0.60	0.55	-	1.15
Taos	0.23	-	*	1.62	-	1.85
Amarillo, TX	-	-	1.68	0.26	-	1.94
El Paso, TX	-	T	0.13	0.92	0.02	1.07

*Amount included in following day.

Rainfall Table A

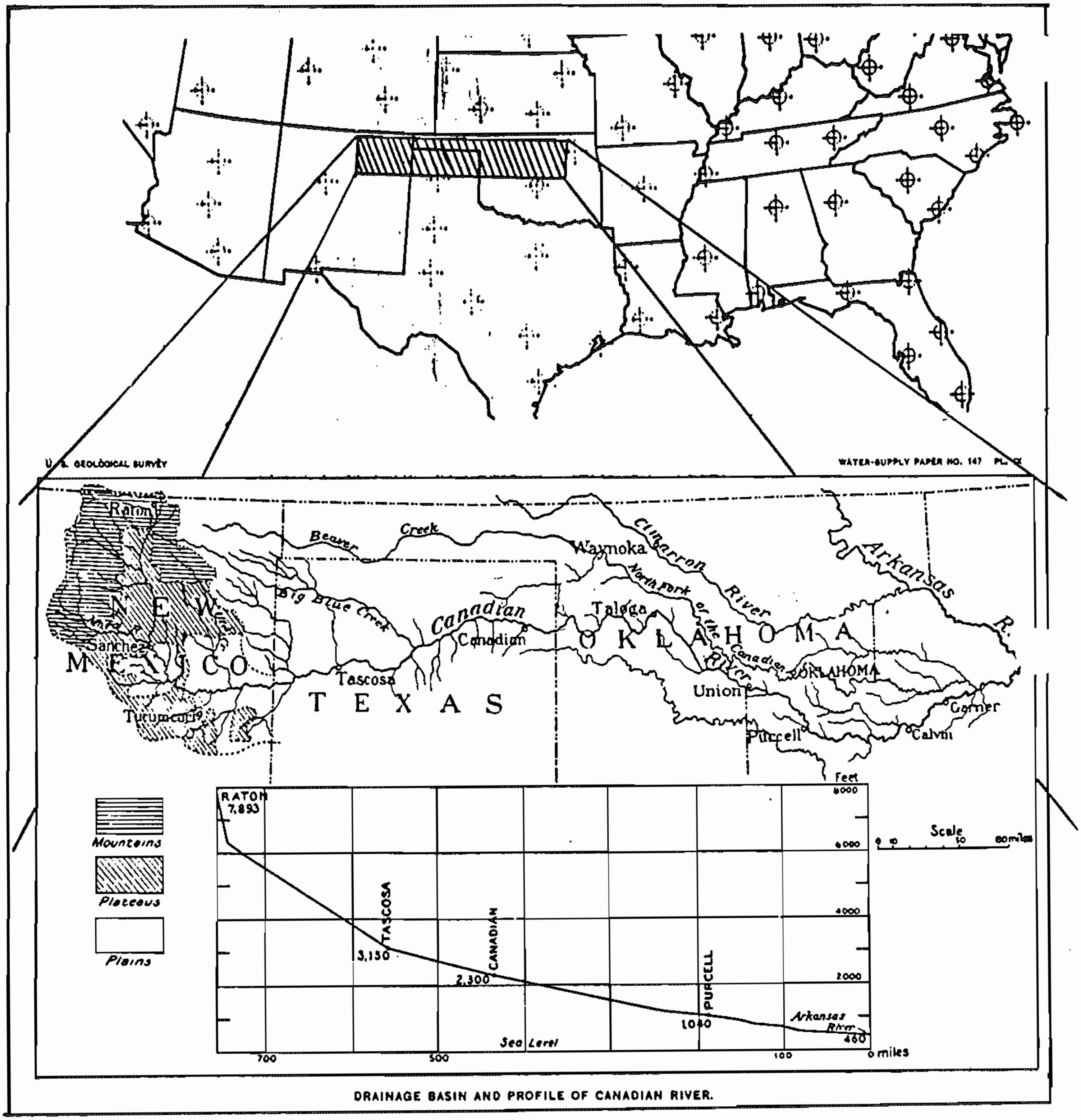
NEW MEXICO PRECIPITATION SPETEMBER 1904
(Canadian Basin Only)

STATION	26th	27th	28th	29th	30th	Total
Albert	0.10	-	0.22	2.40	1.54	4.24
Bell Ranch	-	-	T	2.17	1.87	4.04
Dorsey	-	0.50	0.96	2.65	2.77	6.88
Fort Union	1.80	0.70	1.50	2.30	-	6.30
Raton	1.50	0.80	1.10	3.88	-	7.38
Rociada	T	0.60	*	4.52	2.80	7.92
Springer	-	0.50	0.30	3.10	1.50	5.40
Vermejo	0.05	0.37	0.63	2.30	1.60	4.95
W. S. Ranch	0.86	0.62	1.50	3.67	0.01	6.66

Average = 5.97

*Amount included in following day.

Rainfall Table B



The Canadian River Valley

THE SACRAMENTO RIVER FLOOD OF 1907

**** *All farmers in flooded sections had received warnings from the Weather Bureau, and had ample time to remove stock to places of safety. No stock lost in Colusa County. A copy of all warnings furnished to the press and posted on Market Street and on Fifth Street, and all farmers accessible by telephone notified. The service furnished by the Weather Bureau very satisfactory and greatly appreciated by all interests.*

From correspondence furnished by U.S. Weather Bureau cooperative observer at Colusa, California, following the great winter flood in the Sacramento River Valley of 1907. ****

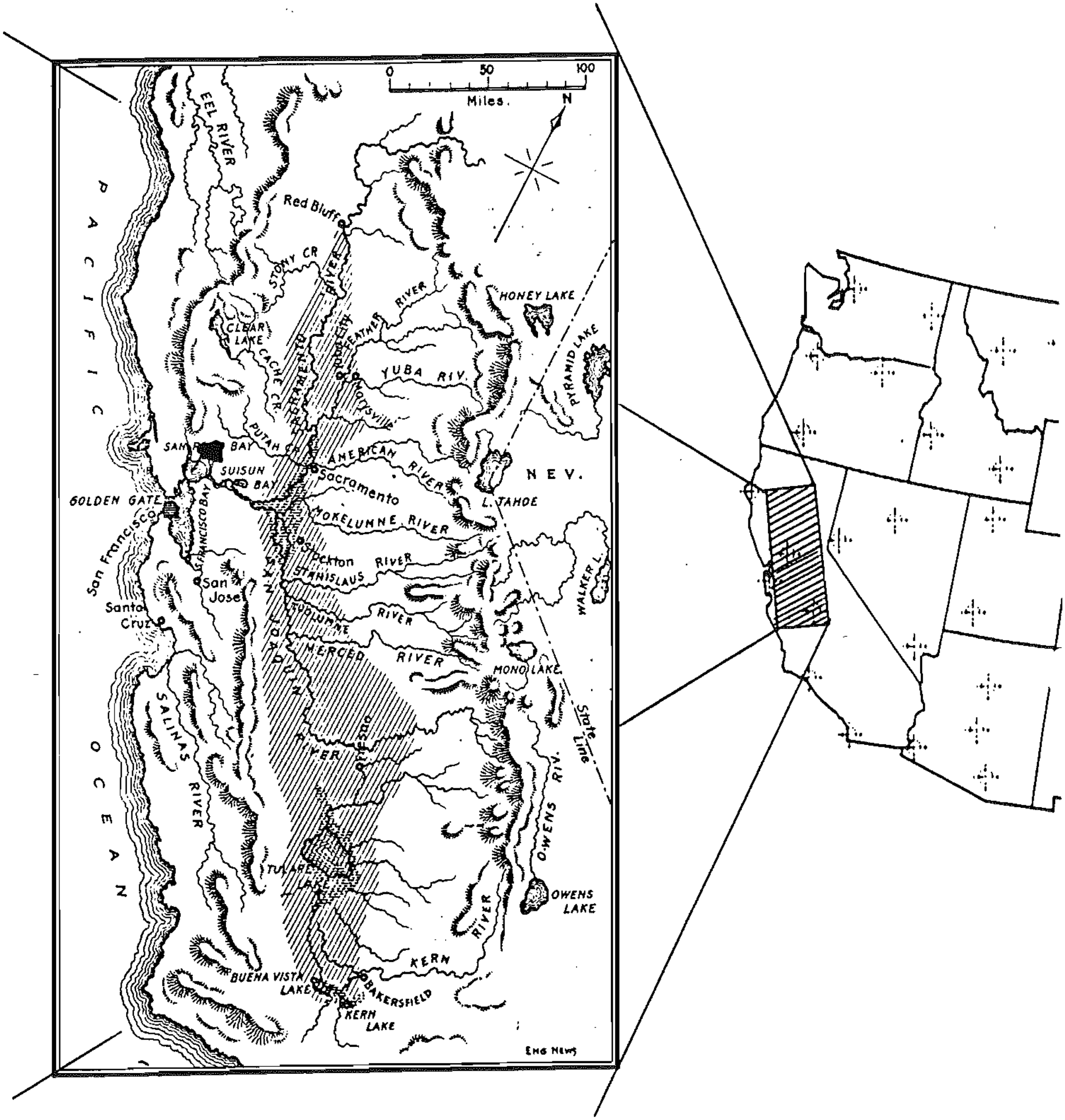
A 1904 PREVIEW

The January through March winter of 1904 in Northern California's Sacramento River Valley was excessively rainy, culminating in serious floods in March in the Yolo, Sacramento, and lower San Joaquin basins. Especially copious February rains, while not themselves resulting in disastrous flooding, served to saturate the valley, leaving great volumes of water in storage, and setting the stage for the agriculturally damaging floods that followed during an equally rainy March. While the 1904 floods in the Sacramento Valley were bad, they served mainly as a preview to the major event that followed exactly three years later.

THE PRECIPITATION OF 1907

The 1907 floods in the lowlands of the Sacramento Valley were without precedent at that time in Northern California. Rainfalls were similar in magnitude to those during the 1904 January through March siege, but runoff was significantly augmented in March of 1907 by melting snows from the valley's surrounding mountain drainages. The result was a flood whose magnitude and duration exceeded not only that of 1904, but any previously known flood for the valley since the settlement of that region. Several "great floods" had occurred during the last half of the nineteenth century; it is probable that the horrendous volume of water discharged during the 1907 flood exceeded any of those.

Winter rains began January 2, 1907, continuing until the 17th. A second rainy period ran from January 24 to February 4 over the valley's lowlands with heavy, accumulating snows in the higher Sierra Nevada headwater basins. The first period's precipitation produced ordinary winter stages in the Sacramento watershed, and began to fill the great overflow, or storage basins, of the valley's lowlands. Precipitation of the second period produced flood stages in all streams of the Sacramento watershed. Overall, however, this flood did relatively little damage, but significantly left all the valley's great storage basins full. The remainder of February was fairly dry, permitting river flows to decline to their usual winter state.



Sacramento-San Joaquin River Valley, California

March contained two distinct precipitation periods. The first went from the 2nd to the 11th, was only moderately heavy, but deposited fresh snow on the high mountains and well down into the foothills. The second storm period persisted from the 16th to the 25th and was very heavy. It proved to be Northern California's undoing. From the 16th to the 20th, inclusive, the rainfall over the northern half of California, especially over the watersheds of the upper Sacramento, Feather, Yuba, Bear, American, Mokelumne, Calaveras, Stanislaus, and Tuolumne Rivers and over the watersheds of Stony, Cache, and Putah Creeks on the west side of the Sacramento Valley, was accompanied by unusually warm weather, especially at the higher altitudes, causing rapid snowmelt and a resulting calamitous runoff, probably the greatest since the civilized settlement of the valley. As an outstanding example of the copious precipitation, Sterling City received 24.22 inches in the five-day stretch, and 43.38 inches for March; and Laporte measured 22.45 and 42.62 inches respectively for the five-day storm and the month. The three-month (January through March) totals were a whopping 85.55 and 76.27 inches at Sterling City and Laporte, respectively.

LATE MARCH RUNOFF EXCESSIVE

The effects of these rains and snowmelt were nearly immediate, extreme, and devastating for all affected rivers feeding into the great valley. By Monday, March 18, 1907, amidst a great deal of damage already, it was clear the valley was in for a monstrous disaster; and the rains were continuing to pound away. Although most telegraph wires were down by now, and any other form of communication was tenuous at best, the Weather Bureau was credited in the flood's aftermath of having furnished vital warnings of worth practically beyond measure.

Mr. J. M. Eddy, Secretary of the Stockton, California, Chamber of Commerce wrote April 4, 1907 to the Weather Bureau Office in Sacramento:

> *In behalf of this Chamber of Commerce and the vested interests of this community, I wish to thank you for your successful efforts to keep this organization and our people apprised of the river stages and weather conditions during the recent floods, and to assure you that there is a very high appreciation of your work among those best informed and most concerned. I trust that the memory of this will influence our citizens to a greater degree of helpfulness to you in making your inquiries in the future.*

Similar plaudits on the performance of the fledgling Weather Bureau during this singularly devastating flood event came from every quarter of the many beleaguered Northern California communities.

Most headwater streams in the valley had crested as the rains began to abate after March 22; and interest began to center on the lowland agricultural areas, in the so-called "island districts," where water continued to rise steadily. The lowland situation was growing desperate, but the only response that could be given to the doomed lowland interests was: "The worst is yet to come. The danger will not decline for another week." Saturday, March 23, was a terrible day when thousands of acres in the highest state of intensive cultivation were inundated. Tidal action was affecting the inundation in these lowlands; and levees which had strained for many days against heretofore untested pressures breached, and tens of thousands of acreage went under at a time.

Finally, by March 29 the valley's waterways were everywhere receding, and it could be considered to be the end of the ordeal.

Nearly 300,000 acres of prime agricultural land had been inundated. Losses were in the millions of dollars. Untold damage to railroads and other forms of transportation had occurred. Fortunately, very few lives were lost, and none were charged directly to the flood.

All previous high-water records were surpassed at all points reporting on the Feather, Yuba, and Bear Rivers, and at all points on the Sacramento River except Red Bluff and Sacramento. The Mokelumne, Calaveras, Stanislaus, and Tuolumne Rivers all passed previous records, as did the San Joaquin below the mouth of the Tuolumne.

FLOOD SPARKED DEBATE

There was considerable debate following the 1907 flood as to whether or not great floods in the Sacramento Valley could ever be controlled. Many experts believed the unusually heavy rains of 1904 had resulted in flows of a magnitude not to be exceeded. To their dismay and bewilderment, the flood flows during the 1907 flood were generally much worse. The tremendous volumes of water which came down during the March 1907 flood, following two months of unusually wet weather already, could hardly have been stored, regardless of what control structures might have been in place. Many officials wisely realized that much more needed to be known at that time about flood flow magnitude and frequency than the day's rather skimpy data base could provide, before any large-scale steps could be taken to afford the valley some degree of flood protection against the floods which would undoubtedly follow that of 1907.

PRECIPITATION -- SACRAMENTO VALLEY, CALIFORNIA

SACRAMENTO BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Delta	1138	1904	3.96	21.19	23.93	49.08	
		1907	12.26	9.21	24.45	45.92	18.10
Redding	565	1904	2.34	14.10	15.89	32.33	
		1907	8.57	9.09	7.28	24.94	4.57
Dunsmuir	2285	1904	5.03	24.00	22.90	51.93	
		1907	20.53	8.27	18.64	47.44	13.61
Sisson	3555	1904	3.26	10.91	15.90	30.07	
		1907	9.48	2.84	13.16	25.48	11.27
Nimshew	2000	1904	10.82	8.72	13.27	32.81	
		1907	17.64	13.12	27.69	58.45	18.36
Sacramento	71	1904	0.45	5.26	5.43	11.14	
		1907	4.63	2.37	7.28	14.28	4.75
Fruto	624	1904	0.75	6.13	7.07	13.95	
		1907	6.43	1.95	4.67	13.05	2.90
Shasta	1148	1904	2.79	24.86	16.37	44.02	
		1907	13.65	7.89	14.47	36.10	10.98
Corning	277	1904	0.60	4.95	7.30	12.85	
		1907	3.60	2.60	5.05	11.25	2.68
Red Bluff	307	1904	1.44	6.63	8.33	16.40	
		1907	6.10	3.13	5.92	15.15	2.93
Tehama	220	1904	1.01	4.67	7.19	12.87	
		1907	4.75	2.96	5.38	13.09	2.79
Chico	189	1904	0.80	5.64	9.33	15.77	
		1907	6.28	2.09	8.03	18.67	4.79
Durham	160	1904	1.70	5.75	10.32	17.77	
		1907	6.45	2.09	8.39	16.93	4.49
Willows	136	1904	0.45	3.44	7.61	11.50	
		1907	4.84	1.02	3.63	9.48	1.98
Colusa	60	1904	0.66	3.13	5.67	9.46	
		1907	5.63	0.75	3.80	10.18	2.21
Suisun	20	1904	1.12	6.50	7.52	15.14	
		1907	8.89	3.59	7.57	20.05	5.95
Dunnigan	65	1904	0.66	5.33	8.87	14.86	
		1907	7.63	1.63	6.98	16.24	3.91

AMERICAN BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Colfax	2421	1904	3.50	20.10	20.46	44.06	
		1907	9.45	9.75	19.46	38.66	12.36
Emigrant Gap	5230	1904	3.75	25.10	31.22	60.07	
		1907	14.35	14.45	30.20	59.00	19.45
Georgetown	2650	1904	4.79	26.02	21.17	51.96	
		1907	8.96	13.50	29.07	51.53	19.47
Placerville	2109	1904	2.96	15.59	13.48	32.03	
		1907	8.13	8.15	20.54	36.82	14.62

AMERICAN BASIN (Continued)

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Rocklin	249	1904	1.29	7.94	2.18	16.41	
		1907	5.51	5.71	12.46	23.68	8.65
Auburn	1360	1904	2.73	13.34	11.83	27.90	
		1907	8.35	9.70	16.66	34.71	11.23
Blue Canyon	4695	1904	4.81	30.61	26.14	61.56	
		1907	13.18	17.95	35.11	66.24	27.33
Iowa Hill	2825	1904	4.58	20.20	16.97	41.75	
		1907	11.52	10.13	24.36	46.01	16.35
New Castle	970	1904	1.93	10.79	11.61	24.33	
		1907	7.09	6.72	14.10	27.91	8.49
Folsom	252	1904	1.12	7.19	7.70	16.01	
		1907	5.25	5.65	11.06	21.96	7.33
Towle	3704	1904	3.84	25.50	23.29	52.63	
		1907	9.45	12.24	24.05	45.74	15.83
Magalia	2321	1904	3.43	23.39	30.13	56.95	
		1907	23.57	10.71	37.75	72.03	24.42
Oroville	250	1904	1.60	7.99	10.86	20.45	
		1907	6.71	3.59	10.90	21.20	5.57
Butte Valley	4020	1904	4.20	22.90	22.10	49.20	
		1907	11.96	6.78	26.76	45.50	----
Greenville	3600	1904	2.39	18.81	15.53	36.73	
		1907	9.57	4.48	24.51	38.56	19.89
Quincy	3400	1904	2.46	22.10	10.83	35.39	
		1907	11.89	4.96	30.15	47.00	25.55
Biggs	98	1904	1.09	4.98	8.35	14.42	
		1907	4.55	1.85	6.57	12.97	3.65
Brush Creek	2140	1904	4.81	23.11	25.01	52.93	
		1907	16.21	11.49	33.02	60.72	23.96
Marysville	67	1904	1.19	5.18	9.77	14.14	
		1907	4.52	4.30	10.59	19.41	6.44
Palermo	213	1904	1.48	7.22	9.35	18.05	
		1907	5.36	3.34	8.80	17.50	4.37
Sterling City	3525	1904	3.96	26.51	25.22	55.69	
		1907	24.63	17.54	43.38	85.55	32.86

MOKELUMNE BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Electra	725	1904	2.61	13.92	9.50	26.03	
		1907	7.47	5.15	18.01	30.63	10.04
Galt	49	1904	0.60	6.24	5.27	12.11	
		1907	4.00	3.29	7.59	15.38	5.92
Ione	287	1904	0.90	7.05	5.00	12.95	
		1907	4.87	3.95	10.39	19.21	6.27
Lodi	35	1904	0.72	5.77	4.85	11.34	
		1907	3.94	2.82	6.76	13.52	4.26

TUOLUMNE BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Jamestown	1471	1904	1.96	12.96	8.18	23.10	
		1907	7.82	5.59	17.27	30.58	10.68
Modesto	90	1904	0.33	1.67	2.15	4.15	
		1907	4.11	3.00	4.70	11.81	3.64
Sonora	1900	1904	1.79	13.82	8.63	24.24	
		1907	7.38	5.40	19.09	31.87	12.17

CALAVERAS BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Milton	660	1904	0.93	6.78	5.30	13.01	
		1907	4.76	2.53	9.27	16.56	4.90
Valley Springs	673	1904	1.42	10.56	7.81	19.79	
		1907	5.51	4.31	11.12	20.94	6.66

STANISLAUS BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Oakdale	156	1904	0.70	5.00	3.44	9.14	
		1907	3.72	2.36	6.37	12.45	3.36

CACHE CREEK BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Upper Lake	1350	1904	1.62	11.19	10.14	22.95	
		1907	5.30	4.60	10.63	20.53	7.98
Guinda	350	1904	0.75	6.80	7.55	15.10	
		1907	9.30	1.30	8.84	19.44	7.20

BEAR RIVER BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Wheatland	84	1904	1.09	6.14	7.22	14.45	
		1907	4.67	3.06	9.64	17.37	6.19

PUTAH CREEK BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Davisville	51	1904	0.53	5.05	7.57	13.15	
		1907	4.81	2.28	6.69	13.78	5.24
Calistoga	363	1904	2.65	16.08	16.10	34.83	
		1907	10.89	7.95	19.50	38.34	16.60
Helen Mine	2750	1904	4.52	34.22	31.48	70.22	
		1907	27.21	11.66	36.73	75.60	28.90
Vacaville	175	1904	1.67	8.61	11.73	22.01	
		1907	6.54	3.08	8.48	18.10	4.81

YUBA BASIN

STATION	ELEVATION		JAN	FEB	MAR	TOTAL	MAR 17-26
Dobbins	1650	1904	3.79	14.04	13.65	31.48	
		1907	10.54	8.98	19.43	38.95	13.04
Nevada City	2580	1904	2.76	19.17	18.64	40.57	
		1907	10.21	8.22	24.62	43.05	17.76
No. Bloomfield	3200	1904	3.85	16.44	21.89	42.18	
		1907	10.25	9.23	28.64	48.12	21.10
Cisco	5939	1904	5.20	30.80	26.87	62.87	
		1907	14.70	6.25	24.20	45.15	14.10
Summit	7017	1904	4.20	30.40	21.30	55.90	
		1907	13.50	4.38	27.36	45.24	16.06
Laporte	5000	1904	4.48	30.35	31.66	66.49	
		1907	17.75	16.40	42.62	76.27	33.12
Bowman's Dam	5500	1904	5.37	45.61	39.51	90.49	
		1907	13.82	12.68	31.46	57.96	-----

	1904	1907
Sacramento River Discharges (Maximum)		
Below mouth, Stony Creek	180,000 CFS	261,000 CFS
Below mouth, Feather River	190,000 CFS	466,000 CFS
Below mouth, American River	230,000 CFS	559,000 CFS
Below mouth, Cache Slough	250,000 CFS	640,000 CFS

Four-day mean flow March 18-21, 1907, at Cache Slough = 555,000 CFS
Four-day mean flow was 85% of maximum 640,000 CFS.

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2. *Monthly Weather Review and Annual Summary*, Volume XXXV - 1907; page 107-108.

3. *Monthly Weather Review and Annual Summary*, Volume XXXII - 1904; page 108.

4. *Engineering News*, December 9, 1909; Page 647; "Flood Prevention and Land Fertilization by Basin Irrigation in the Sacramento-San Jouquin Valley."

THE 1908 AND 1888 FLOODS ON THE SAVANNAH RIVER AT AUGUSTA, GEORGIA

A HISTORICALLY PROMINENT WATERWAY

The Savannah River, forming a natural boundary between the states of South Carolina and Georgia, is one of the most significant rivers in the southeast. With its headwaters in the southern Appalachians, it drains one of the rainiest areas in the continental United States, one where average annual precipitation exceeds 50 inches. Historically the Savannah became a major waterway for colonial Georgia; and not long after the establishment of the town of Savannah on the Atlantic coast, pioneer settlers worked their way up the vigorous river and soon founded settlements in the Savannah's upper valley, including Augusta on the river's right bank, which quickly grew to be Georgia's second city for many years.

While the Savannah River was the highway inland which prompted Augusta's early settlement and provided the town with its relatively easy communications with settlements downstate, it also proved to be a sporadic nemesis to the town when either persistent winter rains or copious downpours during the tropical season sent the river into a frenzied state of flood.

The first well-known flood to beleaguer the young city with unwanted water was that of January 1796. This flood, which probably first fully awakened Augusta citizenry to the devastation potential of their otherwise largely beneficial river, quickly became a legend in local lore and was quaintly sobriqueted as the "Yazoo Freshet." (This somewhat quizzical tag derived from the flood occurring while the Georgia legislature was convened to investigate the alleged fraudulent Yazoo Valley land deal.) Perhaps no one thought the magnitude of the Yazoo Freshet could be approached; but after 44 years, the "Harrison Freshet" of May 1840 again seriously overflowed the town, cresting at 37.8 feet. Then, in quicker succession, floods of note occurred in August 1852 and January 1865 when the river crested at 37.4 feet and 36.9 feet, respectively, each time overflowing into the town.

THE 1888 FLOOD

By now Augusta residents were rightfully growing wary of the Savannah and watched fearfully in first July and then August of 1887 when tropical rains sent the river first to 34.6 feet and then to 34.3 feet. While these two rises during the summer of 1887 were threatening, neither caused widespread flooding of the city and only served as a preview of 1888's flood when the river at Augusta crested on September 11 at 38.7 feet. This was the greatest recorded flood up to that time since the city's river gage had been installed in 1835.

The summary in the September 1888 *Monthly Weather Review* (2) is brief, but hints effectively of the flood's crippling effect on Augusta: "Augusta, Ga., 10th: a flood is now desolating this city. The streets are filled with water to a depth of several feet, causing an entire suspension of business. In the freshet of 1840, the severest previously experienced, the water did not reach its present height by fifteen inches."

Early risers on the morning of September 10, following the previous day's drenching rains, found the river flowing at near bankful and rising steadily. By noon it was clear the town would be engulfed, and by sunset the river had risen to 37 feet 8 inches. At this time the city bridge was swept away with the gage, and the river's continued rise to crest was estimated.

An after the fact account of the flooding in Augusta is provided by the September 13, 1888, *Charleston News and Courier.*

> *Augusta is safe again after the biggest and most disastrous flood on record. The Savannah River has subsided after rising over 38 feet and inundating the whole of the business part of the city, but it leaves scars which a million dollars will hardly heal. Streets are torn up and bridges washed away.*
>
> *Fatalities are few, and the deaths this morning, so far reported, are nine.*
>
> *Augusta had no gas or electric lights for two nights. The electric lights are on tonight, and the gas will be ready tomorrow. All railroads are badly damaged in the city, but the greatest sufferer is Georgia Road, whose shops, yard and headquarters are here. Tracks are swept up and mingled up as if they were straws, and bridges and canals are torn up.*
>
> *The water is still in the low places, but is rapidly sinking to the river bed. The suffering has been great, but Augusta is able to care for all. Augusta is plucky and enterprising, and will not only repair her streets and the canal, but carry the Exposition straight on to success, and be ready to receive and entertain all visitors in October.*

Augustans did clean up, repaired, and held their October Exposition while the Savannah River continued to recede to a more sane state.

The track of the tropical storm which brought the rainfalls for this flood is clearly shown in (1), The U.S. Weather Bureau's North Atlantic Hurricane Tracking Chart (Figure 1).

THE FLOOD OF 1908

For the next 20 years the river was fairly well-behaved. Only a few winter rises posed threats to the city, but the town escaped general overflows until August 1908 when a tropical disturbance, less well-defined than 1888's, brought copious rains to a large section of the southeast, and especially to the 7,232-square-mile drainage of the Savannah Valley above Augusta ((9), Figure 2).

According to August 1908's *Monthly Weather Review* (3), "Disastrous floods occurred during the last decade of August in the rivers of Georgia, North Carolina, and South Carolina. . . . The floods were attributable to heavy and widespread rains, especially over the southern Appalachian

Mountains. . . . Warnings were issued well in advance of the floods and resulted in the saving of many lives and the protection of much movable property."

The following editorial is taken from the *Baltimore American* of August 28, 1908.

> *Augusta has been visited by the sweep of the tempest, the storms of Wednesday and Thursday making wide wreckage and creating tremendous losses in the southern city. There is naturally a great deal of suffering attending the destruction of property and commodity values, estimated at a million dollars. Hundreds of persons are homeless and many have been thrown out of employment. The Savannah River played havoc with the property lining its banks. Its overflow inundated the city and caused the citizens to take to the boats provided for their rescue.*
>
> *The value of the Weather Bureau to flood-threatened communities was shown in the warnings issued Tuesday morning that the river, by the following evening, would rise 35 to 37 feet. The citizens, thus forewarned, took to the hills, and many saved their household effects by acting on the prediction.*

At Augusta on August 27, 1908, at about 2:00 AM, the river crested at its then highest observed stage in history of 38.8 feet, 0.1 foot higher than 1888's September freshet. The river remained at a stand for about three hours; but by the following morning, the stage had receded to 33 feet, permitting again some movement about the town.

LEVEE PROVIDES RELIEF

This last great Savannah River flood, when viewed with its twin of 1888, served to convince Augustans that the continued prosperity of their city required protection against these periodic rampages of their river. While the prospects of a protecting levee had been argued for 20 years, its cost to the city loomed too great for bond approval. The 1908 flood, however, demonstrating that twice within a 20-year period the river could devastate the town, tipped the scales of public opinion and loosened the purse strings. Discussions and plans for a levee to protect Augusta from floods of the magnitude of both 1888 and 1908 began in earnest. Any lingering doubts about the city's need for the levee were dispelled by a damaging winter flood in March 1912, when the Savannah rose to a 36.8 foot crest, and actual construction of the levee began around 1913 (5). Largely finished within about three years, the levee fully proved its worth to Augusta during September and October of 1929 when, as described by *Monthly Weather Review* (6), within the space of one week the Savannah went on a double pronged record rise, cresting first on September 27 at a leveed stage of 46.3 feet, and after a significant recession, rising again on October 2 to 45.1 feet. The levee held for the most part and spared Augusta from flood devastations that would surely have eclipsed the city's watery woes of both 1888 and 1908.

The great levee wall was built before the days of substantial federal aid for such projects and was financed almost completely by local funds. Prying loose those funds was no easy task for a town such as Augusta, but the 1888 and 1908 floods convinced the city leaders that their town's future well-being depended upon a significant measure of freedom from the Savannah's overflows, which more than 120 years of river watching revealed would be all too frequent and severe. Table 1 shows the dates of some of the most significant floods to have occurred from 1796 through 1940 (4).

REFERENCES

(1) *Tropical Cyclones of the North Atlantic Ocean, 1871-1986* - U.S. Department of Commerce, NOAA, NWS, NESDIS; Historical Climatology Series 6-2.

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(3) U.S. Weather Bureau - *Monthly Weather Review*; August 1908; page 233.

(4) U.S.G.S. Water Supply Paper 1673 Part 2-A; 1960.

(5) *Engineering News*, Vol. 72, No. 6; "The Savannah River Levee, Augusta, Georgia," by Nisbet Wingfield; August 6, 1914; page 277.

(6) U.S. Weather Bureau - *Monthly Weather Review*; October 1929; page 435.

(7) *Memorial History of Augusta, Georgia -- Georgia Heritage Series No. 3*; Jones and Dutcher, page 190.

(8) *U.S. Weather Bureau - Daily River Stages, Principal Rivers of the United States*; Volumes for 1908, 1929.

(9) *Storm Rainfall of Eastern United States (Revised)*, State of Ohio - The Miami Conservancy District, by the Engineering Staff of the District; Technical Reports Part V; Dayton, Ohio; 1936.

TABLE 1. SAVANNAH RIVER AT AUGUSTA, GA

YEAR	DATE	MAXIMUM STAGE (FT)	DISCHARGE (CFS)
1796	January	*	
1840	May 28	37.8	270,000
1852	August 29	37.4	250,000
1865	January 11	36.9	240,000
1888	September 11	38.7	303,000
1908	August 27	38.8	307,000
1912	March 17	36.8	234,000
1928	August 17	40.4 **	226,000
1929	September 27	46.3 **	343,000
1929	October 2	45.1 **	350,000
1936	April 8	41.2 **	258,000
1940	August 15	40.9 **	239,000

* Occurred before gaging records were available.

** Occurred after levee was constructed.

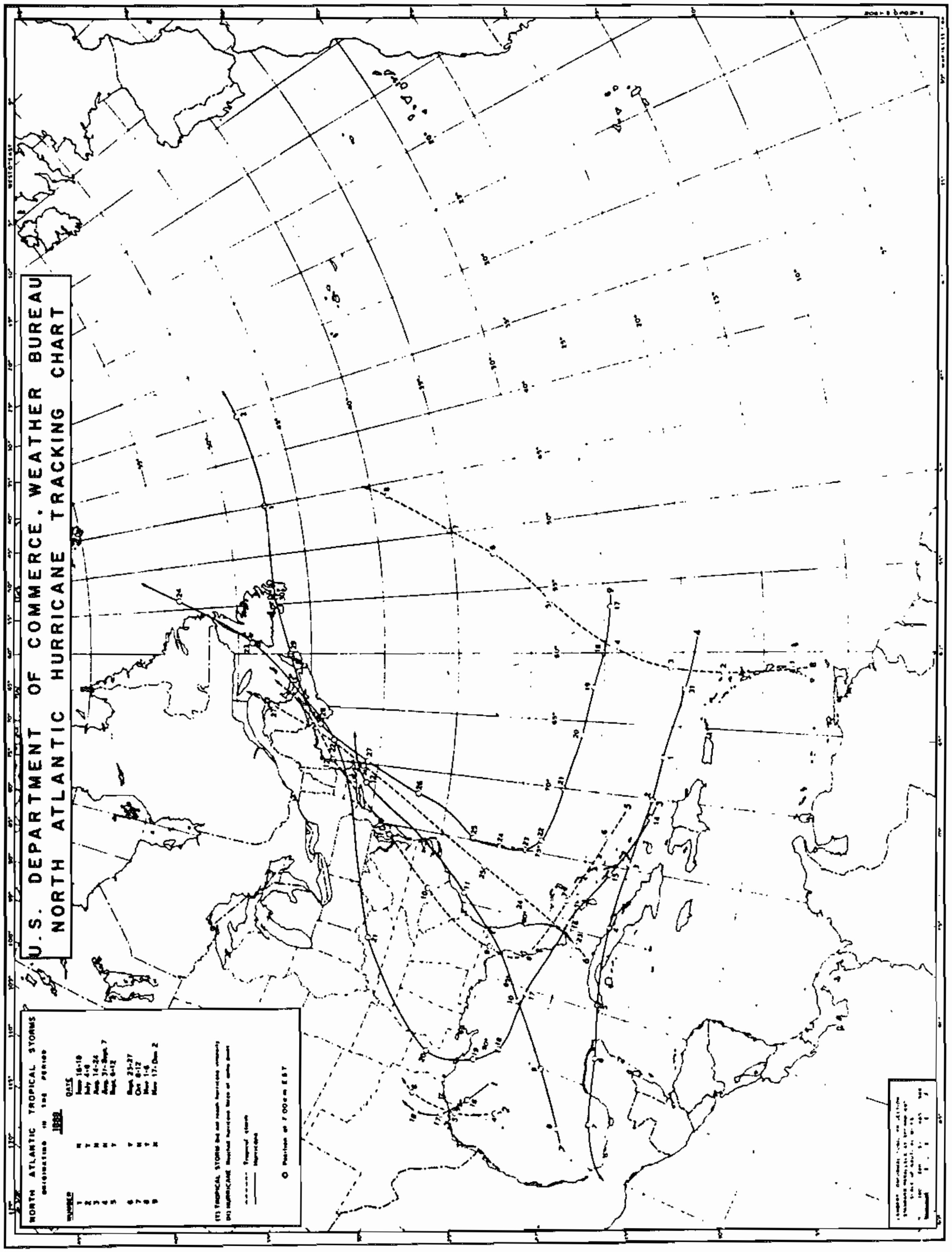
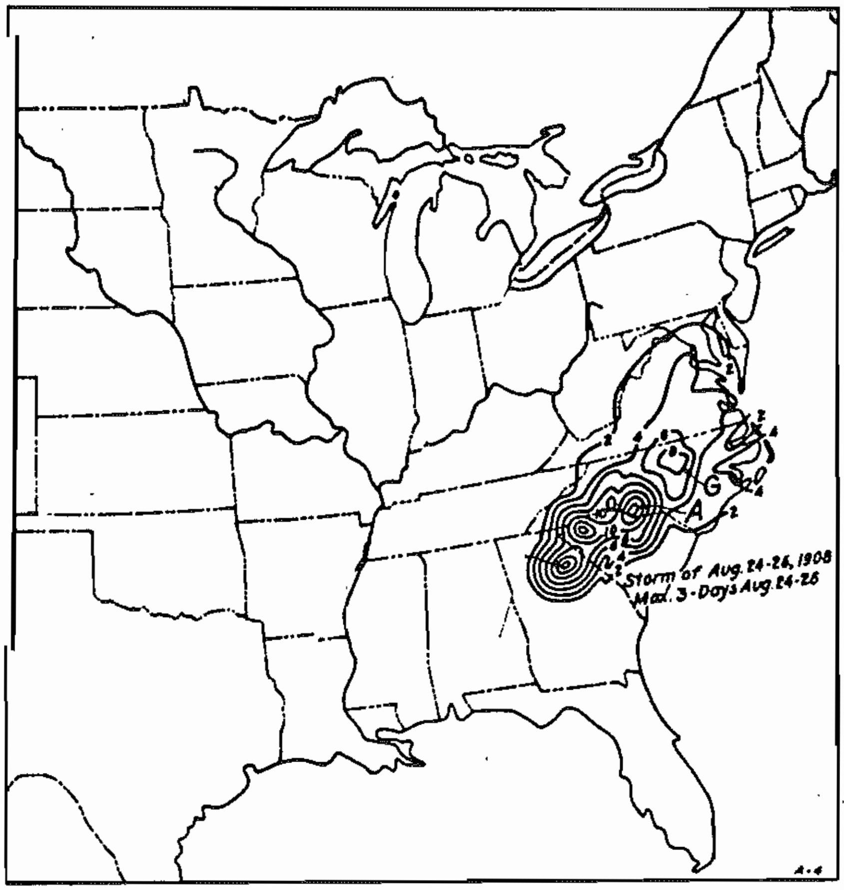

U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
NORTH ATLANTIC HURRICANE TRACKING CHART

Figure 1



Storm 103, August 24-26, 1908

Widespread rains occurred over the south Atlantic states on Aug. 24, 25, and 26, 1908. These were accompanied by heavy downpours over portions of Georgia, and North and South Carolina, see figures 84 to 86. In 3 days 14.75 inches fell at Carlton, Ga., and 14.14 inches at Greenville, S. C. At Anderson, S. C., 14.31 inches fell in 3 days, of which 11.65 inches fell on the 25th. At Monroe, N. C., 15.58 inches fell in 3 days. In the main, however, the rain was distributed quite evenly. The damage done to standing crops and to property along streams was incalculable. Heavy rains on the 19th and 21st of August had partly saturated the soil in many places, and the runoff following this storm was, therefore, very great. On many of the south Atlantic coast streams occurred the highest stages at that time on record. Some of these stages have since been exceeded following the storms of July 1916 in the Appalachian region, described subsequently. The Savannah and Santee Rivers experienced the most destructive floods in their histories, the Savannah at Augusta, Ga., exceeding the great flood of Sept. 11, 1888, by 0.1 foot. The crest stage of 38.8 feet on August 27 is the highest on record in a century. At Calhoun Falls, S. C., the crest stage was 28.2 feet, also the highest on record.

Taken from Reference (9)

Figure 2

COLORADO'S UPPER RIO GRANDE FLOOD OF OCTOBER 1911

INTRODUCTION

Each springtime the melting of snowpacks from the high mountains of southwestern Colorado sends the Upper Rio Grande on a rise with flows cresting sometime between late May and early July. The annual occurrence is routinely expected by all residents of the valley. By late summer, the river flow is generally back down to a minimum, and the river's tranquil state lasts until the following melt season. On very rare occasions, however, this cycle is disrupted. Nineteen eleven was such a year.

THE FLOOD

The greatest flood in recorded history in the uppermost reaches of the Rio Grande Basin in southwestern Colorado occurred October 5-6, 1911. While no flood in the intervening 79 years has eclipsed that autumn inundation, this fact itself speaking strongly of the flood's singularity, the most rare feature yet remains its occurrence in October, an unusual time for high river flows from the stream's source region. Table 1 lists the maximum discharges and their months of occurrence each year for the 50-year period 1900-1949 at Del Norte, Colorado, on the Rio Grande. For that 50-year period, only the 1911 annual maximum failed to occur during the May-July melt season. Figure 1 is the flood discharge hydrograph for the Rio Grande near Del Norte, Colorado, covering the six-day period October 4-9, 1911 (1).

The Rio Grande trunk stream rises in the central part of Hinsdale County, Colorado, and flows easterly emerging from the mountains at Del Norte and then flowing through the heart of the 7,000-foot high San Luis Valley to Alamosa, and then southward into New Mexico (see Figure 3). The character of the region drains a mountainous country ranging in altitude from over 14,000 to 6,000 feet MSL, encompassing some of the highest mountain country in the continental United States. Downpours of rain in that remote high region during the warmer months of the year from local thunderstorms are expected occasionally in the mountains, but the areas affected are usually small. With the coming of autumn, thunderstorms give way to general storms that spread their influence over a wide scope of the country, causing sharp falls in temperature and occasional heavy snowfalls. On October 4 and 5, 1911, instead of these last-named conditions, mild temperatures prevailed as high as or higher than timberline, permitting precipitation in the form of rain rather than snow. Indeed, those rains were widespread, copious, and entirely at fault in producing the worst flood since the settlement of that part of the country.

The widespread heavy rains caused floods also on the Dolores and San Miguel Rivers in western Colorado, the San Juan and its tributaries in Colorado and New Mexico, as well as the Upper Rio Grande in Colorado, and the tributaries of the Rio Grande in northwestern New Mexico on October 5 and 6, 1911. There is no previous record, or even tradition among the native Indians, of such severe floods occurring simultaneously in all the streams of that two-state area.

The San Juan Mountains, which are part of the Continental Divide, form the watershed between the upper Rio Grande on the east, the San Juan on the south, and the Gunnison on the north. It was in this region that the storm was most severe, although there were torrential rains throughout the district. In general, the rains began during the forenoon of the 4th, becoming heavy during the night, and continuing heavy until late in the afternoon of the 5th. There is evidence that the rainfall increased with altitude. The effect of rainfalls of 2.50 inches to more than 8 inches on the steep slopes of the San Juan Mountains was to cause quickly forming floods that swept away everything in their path. Five lives were lost; miles of railroad tracks were destroyed; scores of bridges were carried away; and there was a general destruction of crops, of farm lands by immense deposits of silt or by erosion, wagon roads, trails to the mines, irrigating ditches, flumes, and other mining equipment. It was months before normal conditions of travel could be restored.

An account by Mr. E. T. Walker, Weather Bureau cooperative observer at Pagosa Springs, Colorado, on the San Juan River, is revealing of the severity of conditions during the siege (2).

> *The precipitation beginning at 1 PM on the 4th, and ending at 11 AM on the 5th, totaling 3.82 inches, resulted in the most disastrous flood known within the memory of the oldest inhabitants -- including Indians. The precipitation of the previous few days, viz, September 29, 0.30, September 30, 0.62, October 1, 0.33 inch, had thoroughly soaked the ground, and much of the water ran off. Owing to the constant changing of the channel of the river at this place, it is difficult to gage the rise of the flow with any degree of accuracy, but it is safe to say that twice as much water passed here on the 5th as has ever flowed in any single 24 hours of the 32 years that I have resided on the banks of the San Juan. The precipitation was general throughout the county and resulted in much damage to ranches, roads, bridges, irrigating ditches, railroads, etc.*

News of the flood in the upper parts of the different watersheds was communicated to the downstream points, permitting the taking of steps to minimize as far as possible the damages.

The Rio Grande in flood spread out, and in places was from 2 to 4 miles wide. In Alamosa, the principal damage resulted from the breaking of a dike and the inundation of 30 city blocks. Downstream in New Mexico, where the river bed is of greater capacity, the damage was not as serious.

Flooding from the heavy rains of October 4-5 was undoubtedly made more severe by the fact that widespread rains of nearly an inch over the three-day period September 29 - October 1 had largely saturated the mountain soil, leaving it ill-prepared to accept the heavier rainfalls which precipitated the flooding. Again, Figure 1 is the hydrograph for the flood as it passed Del Norte Colorado.

EASTERN NORTH PACIFIC TROPICAL STORMS

The unfortunate victims of that unprecedented flood in 1911 had no way of knowing that an eastern North Pacific tropical storm, unnamed of course, was the principal culprit in inflicting such misery on one of the mountain west's most scenically-endowed areas. That the rains for that flood were of tropical origin is now widely believed. A strong case is made in studies by Walter Smith (3) which was presented in his 1986 publication, "The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States."

Smith describes the tropical cyclone of October 1-5, 1911, in the following fashion.

> *The storm apparently weakened rapidly on October 4 after moving inland over Baja California just west of La Paz. Nevertheless, moist tropical air was drawn northward ahead of a digging short wave which by 1300 GMT on the 4th was located in northern Nevada. A day later the surface low was situated on the Utah-Arizona border producing heavy rains over the eastern half of Arizona, northwestern New Mexico, southeastern Utah, and southwestern Colorado where torrential rains fell causing a major flood in the San Juan River basin and five fatalities. Gladstone, Colorado, (elevation 3,220 M) reported a total of 8.16 inches of rain, 8.05 of it falling on October 5.*

Figure 2 is Smith's plot of the storm track and isohyets for that October 1-5, 1911, tropical storm. Table 2 shows rainfall data for a number of precipitation stations in both Colorado and New Mexico that were in or near the Upper Rio Grande basin. The data includes not only the flood producing rainfalls of October 4-6, but also the antecedent rainfalls of October 1-2, 1911. Although missing from the map provided, Gladstone, Colorado, at an altitude of nearly 10,000 ft. MSL and shown receiving the phenomenal 8 inches of rainfall, lies just west of the westernmost extension of the Rio Grande basin.

Smith's work clearly points out the significant role of eastern north Pacific tropical cyclones in bringing heavy precipitation and related floods in late summer and early autumn to much of the southwestern United States. He furthermore states that given the rapid growth and urbanization of many cities in the southwest over recent years, these storms will probably cause many serious floods in the future.

Citing a more recent example, his studies point out the occurrence of Tropical Storm Norma of August 30 - September 5, 1970, which brought devastating floods to Arizona and Utah, causing at least 25 deaths. Rains from Norma reached the basin of the Upper Rio Grande as well, and the September 6, 1970, annual record high discharge at Del Norte, Colorado, of 7380 CFS represents a second case since the great flood of October 1911 when the year's greatest flow occurred from autumn rainfall rather than springtime snowmelt. Fortunately for the modern public, and unlike the hapless residents of the Upper Rio Grande in 1911, or even to a lesser degree those of 1970 and Norma, today's weather surveillance technology furnishes a means by which the developing meteorological conditions can be detected in a much more timely fashion.

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Momentary Maximum Annual Discharge 1900-1949
Rio Grande near Del Norte, Colorado

Year	Month	Discharge	Year	Month	Discharge
1900	May	5,450	1925	June	3,610
1901	May	4,480	1926	June	5,450
1902	May	1,790	1927	June	15,000
1903	June	6,020	1928	June	4,900
1904	May	2,040	1929	June	5,830
1905	June	10,000	1930	May	4,400
1906	June	7,670	1931	June	2,670
1907	July	7,770	1932	June	5,460
1908	June	4,130	1933	June	5,050
1909	June	6,980	1934	May	2,980
1910	May	5,260	1935	June	6,520
1911	October	18,000	1936	May	4,000
1912			1937	May	3,920
1913	May	4,030	1938	June	6,560
1914	June	5,820	1939	May	3,550
1915	June	4,690	1940	May	2,810
1916	May	5,020	1941	June	7,960
1917	June	8,790	1942	May	7,150
1918	June	3,820	1943	June	3,380
1919	May	6,020	1944	May	7,070
1920	June	8,100	1945	June	4,030
1921	June	9,630	1946	June	3,860
1922	May	8,320	1947	June	4,390
1923	May	5,210	1948	May	8,840
1924	June	5,980	1949	June	10,000

TABLE 1

DAILY PRECIPITATION FOR SELECTED STATIONS
IN COLORADO AND NEW MEXICO -- OCTOBER 1911

		October 1911						
STATION	STATE	1	2	Σ(1+2)	4	5	6	Σ(4+5+6)
Chama	NM	0.45		0.45	0.40	2.30	0.05	2.75
Chromo	CO	0.45		0.45	0.50	2.00	0.01	2.51
Cumbres	CO		0.30	0.30	3.08	1.26	0.49	4.83
Dulce	NM	0.28		0.28	0.20	1.75		1.95
Durango	CO	0.05	0.02	0.07	1.16	2.26		3.42
Gladstone	CO	1.62	T	1.62	0.11	8.05	T	8.16
Hesperus	CO			0.00		2.30	0.58	2.88
La Veta Pass	CO			0.00	0.59	1.42		2.01
Manassa	CO	0.15		0.15	1.28	0.15		1.43
Mancos	CO	1.12	T	1.12	0.08	1.54		1.62
Pagosa Springs	CO	0.33	0.01	0.34	0.15	3.67		3.82
Platoro	CO	0.61	0.02	0.63	0.05	3.25	0.04	3.34
Saguache	CO			0.00		1.20	0.10	1.30
San Luis	CO	0.02		0.02	0.40	1.50	0.07	1.97
Silverton	CO	0.90	T	0.90	0.20	4.05		4.25
Taos	NM	0.10		0.10	0.27	1.38	0.20	1.85
Telluride	CO	0.96	0.02	0.98	0.02	1.57	0.20	1.79
Wagon Wheel Gap	CO	0.17	T	0.17	0.71	1.94		2.65

TABLE 2

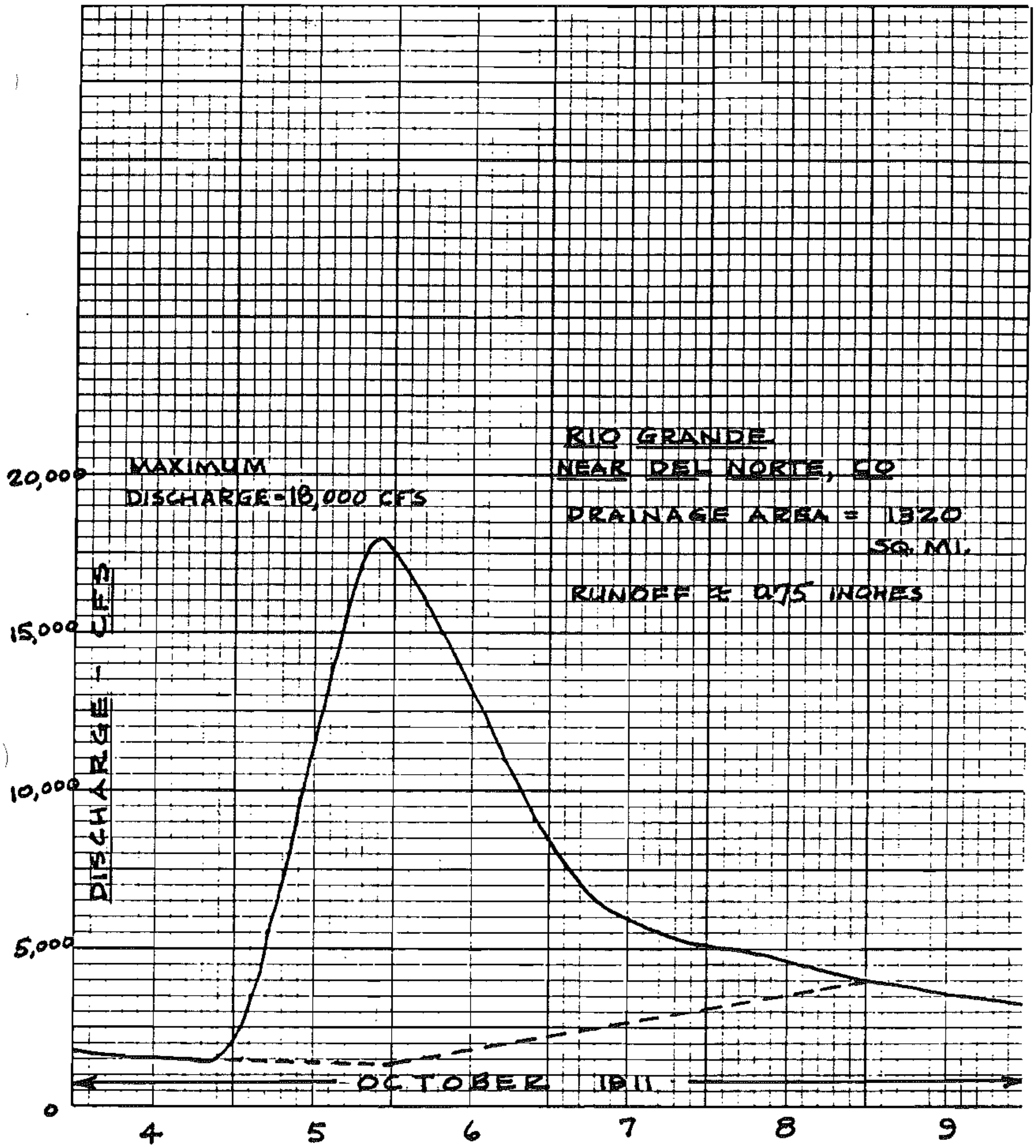

FIGURE 1

Flood Hydrograph for Del Norte, Colorado, October 1911

TROPICAL CYCLONE OF
10/1-5 1911

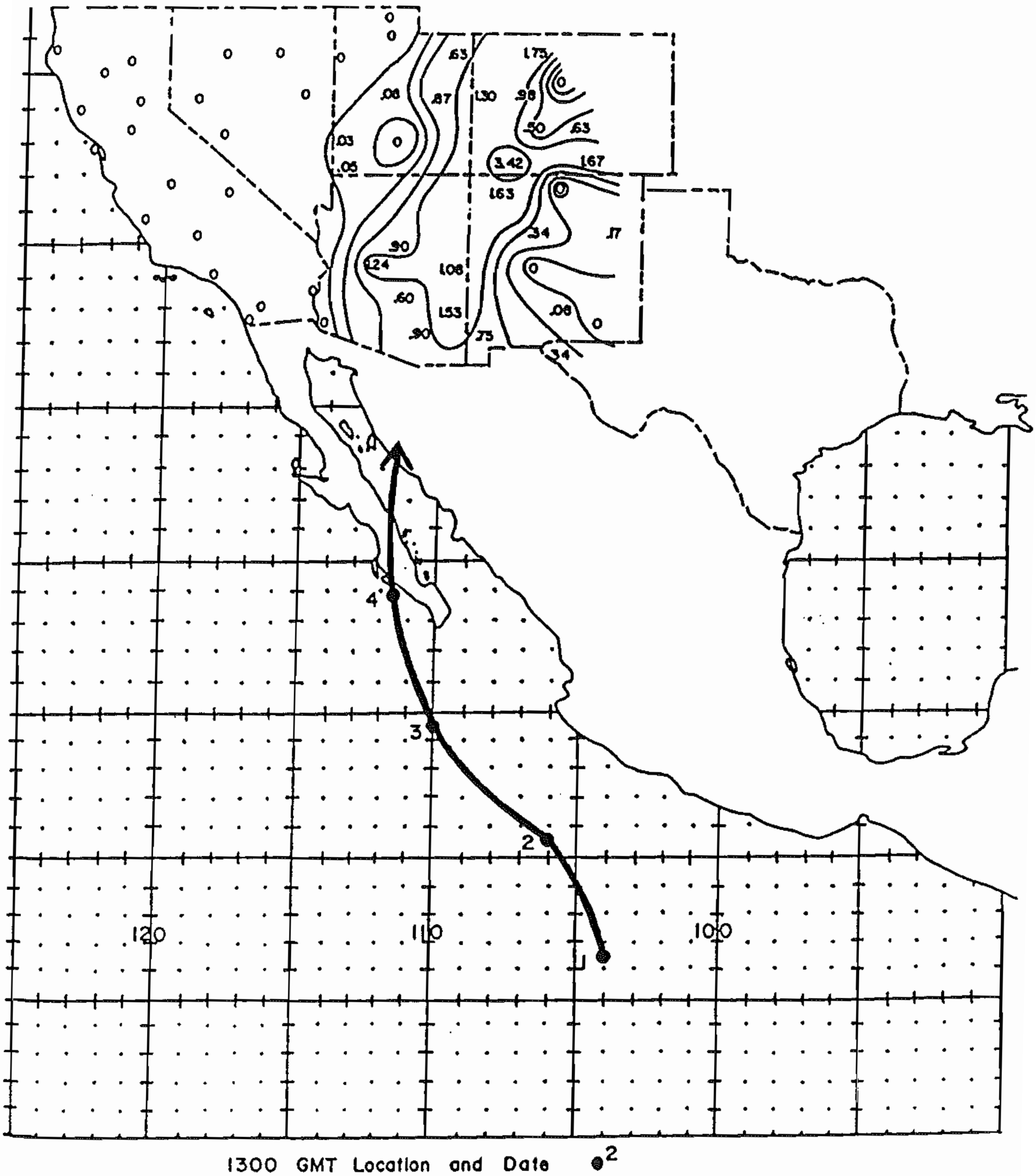

Figure 12. Track of the Tropical Cyclone of October 1-5, 1911 and associated rainfall in the Southwest. Precipitation totals are in inches and the isohyets are drawn at .01, .25, .50, 1.00, and 2.00 inches.

FIGURE 2

From Walter Smith's "The Effects of Eastern North Pacific Tropical Cyclones on the Southwestern United States"

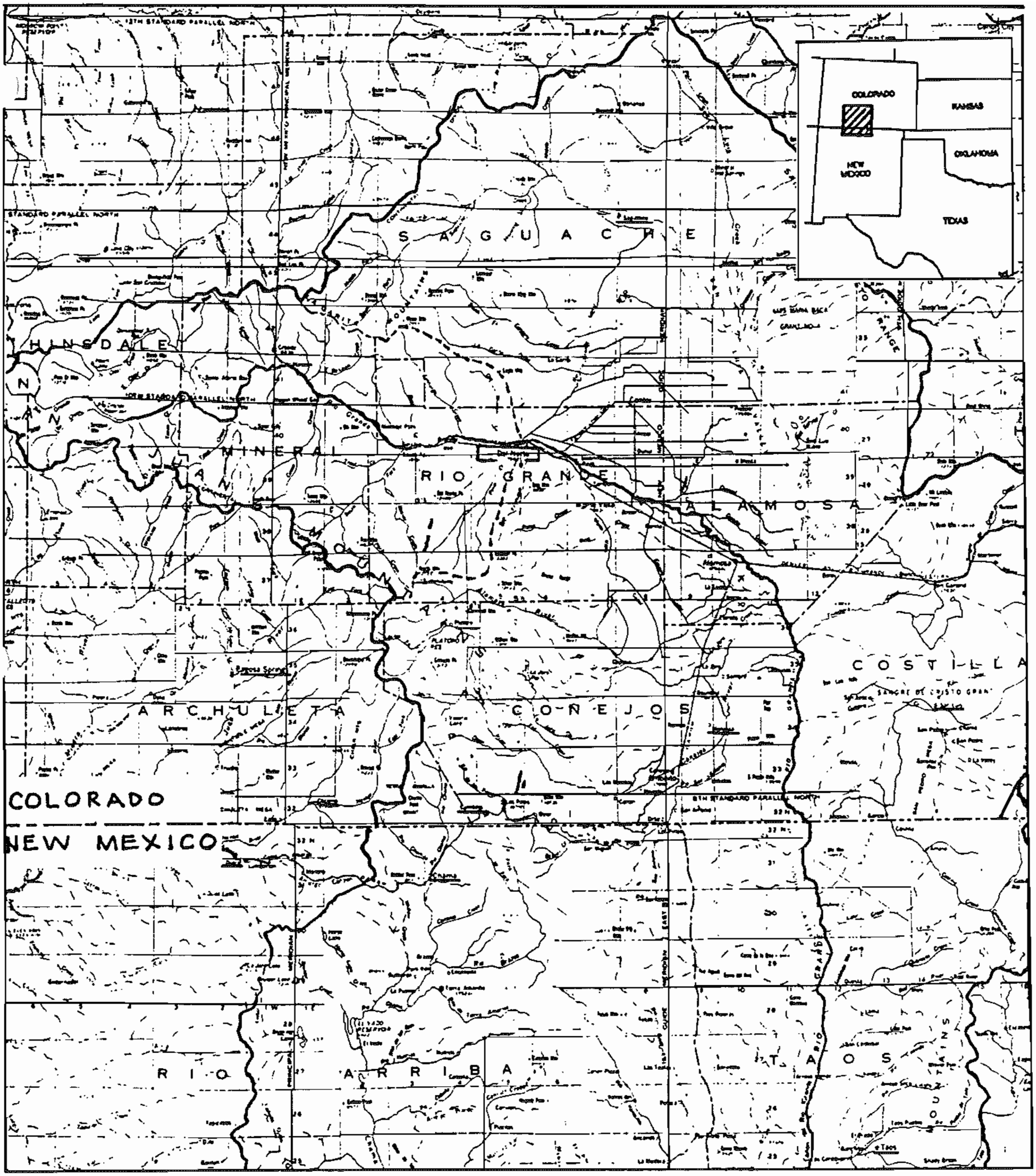
SAGUACHE
HINSDALE
MINERAL
RIO GRANDE
ALAMOSA
COSTILLA
ARCHULETA
CONEJOS
COLORADO
NEW MEXICO
RIO ARRIBA
TAOS
KANSAS
OKLAHOMA
TEXAS

Figure 3

THE 1913 FLOOD ON OHIO'S GREAT MIAMI RIVER

MIAMI RIVER VALLEY VULNERABLE

The state of Ohio's Miami River, sometimes called the Great Miami, drains the southwestern portion of the state. The Miami River empties into the Ohio River at a point about 20 miles downstream of Cincinnati. Dayton and Hamilton are the two major Ohio cities lying along the Miami's banks, with drainages of 2525 square miles above Dayton and 3672 square miles above Hamilton. The terrain features are short and steep, and the mainstream grade is rather flat at about three and one-half feet per mile.

First settled about 1790, the Miami Valley has always demonstrated flood-prone tendencies. Serious floods since 1790 include those of 1805, 1814, 1828, 1832, 1847, 1866, 1883, 1897, and 1898. Finally in March of 1913 occurred the greatest flood disaster to have visited the Miami Valley.

MIAMI VALLEY TOWNS DEVASTATED

Tremendous rainstorms swept the valley from March 23rd until the 27th. All streams in the valley rose rapidly and overtopped the levees in all the valley towns. Thousands of people were marooned for three days and nights in the attics and on the roofs of their dwellings. In Dayton alone, 15,000 buildings comprising the best residential and business sections of the city were inundated by a swirling sea of runoff. The human toll was terrific. Over 400 lives lost were attributed directly to the flood waters. It is also estimated that a like number perished later as a result of exposure during their three-day ordeal. In Dayton it is also said that 30 to 40 citizens became mentally demented as an emotional reaction to the trauma of their situation. While such losses and tragedies were the greatest in Dayton, the valley's largest city, all communities in the valley were left prostrate as a result of the monstrous flood.

In the major city of Dayton, the river rose slowly during the day of Monday, March 24, but with increasing rapidity as night approached. It continued rising through the night at a rate of one to two feet an hour, and at daylight Tuesday was found overflowing the town's levees. Some water was flowing into the city's center at this time. The river continued to rise rapidly, breaking into the business district between 8 AM and 9 AM and continuing to rise until 2 PM when the rate of rise slowed dramatically until its crest about 1:30 AM Wednesday, March 26. At this time, water was 12 feet deep on Dayton's Main Street. It has been estimated that the discharge of the river at Dayton at this time was approaching a quarter of a million cubic feet per second, a remarkable and devastating discharge from a catchment of only 2525 square miles. The river then commenced to fall, and levee tops came once again into sight by Thursday morning, March 27.

The people of Dayton and the Miami Valley accepted both their individual and community losses, and with great determination cleaned up the terrible wreckage and finally reestablished their businesses. Martial law was temporarily declared, and the militia patrolled the streets of the towns. Every able-bodied man was put to work, food was distributed, and tents supplied to the homeless. Railroad and wire lines were rebuilt and communication restored to the valley. A particularly vexing problem was the removal of hundreds of horse carcasses from city streets throughout the valley.

More than a past century of flood experiences, capped by the tragedy of the 1913 monster flood, led the citizenry of the valley to the unified conclusion that calamitous flood losses in their valley must be made to cease. To this end, even while some were still clearing wreckage and debris from the valley cities' streets, others were already engaged in developing a plan to prevent such a tragedy from ever again occurring anywhere in the entire valley.

THE MIAMI CONSERVANCY DISTRICT

Ohio did not have a law that would accommodate such a massive cooperative plan to essentially flood-proof an entire valley. Therefore, a law known as the Conservancy Act of Ohio was prepared and passed by the Ohio Legislature in 1914. The law permitted the formation of Conservancy Districts in Ohio for the purposes of drainage or flood control.

Shortly after this law was signed by the state's Governor, the Miami Conservancy District was established in 1915; and its plan for flood protection, called the Official Plan (7), was approved in 1916. Construction on components of the $17,000,000 plan commenced in January 1918.

Today the Miami Valley is almost totally free of great damaging floods as a result of the flood control works of that Official Plan. The Plan consisted largely of the construction of five flood-control-only reservoirs, levee and channel improvements, the construction of several storm sewers, and many minor pieces of work. The bulk of the work was completed by 1922. Since that time, there have been no more damaging floods in the Miami Valley.

Although no storms equaling or exceeding the 1913 deluge have been repeated over the Miami Valley, January 1937 provided a stern test for the "flood-proofed" valley. Overall, the Ohio Valley suffered the greatest flood in its history January 1937, when massive rains swept the greater portion of the entire Ohio River Valley. There were four distinct rises over a two-week period on the smaller Miami River, January 13-26; but the river stages at both Dayton and Hamilton reached only one-half what had occurred in 1913, although rainfall totals for the 1913 and 1937 storms over the Miami Valley were almost equivalent.

The January 28, 1937, *Engineering News Record* reported on the successful performance of the Conservancy District's dam and levee system in the following fashion:

> *The only comprehensive flood control system in the Ohio Valley, the Miami Conservancy system, met a severe test at peak flow of the Great Miami River system last week. It functioned with complete success, according to C. H. Eiffert, Chief Engineer of the Conservancy District.*

Eleven-day rainfall at Dayton, January 13-24, 1937, representative of precipitation conditions over the river basin, totaled 9.59 inches. The five retarding dams of the system impounded water to the following depths:

Englewood	*54.7 ft.*
Germantown	*51.8 ft.*
Taylorsville	*26.9 ft.*
Huffman	*24.0 ft.*
Lockington	*29.7 ft.*

These stages were evidently exceeded during different prior occasions, but the combination of reservoir discharges exceeded that ever before experienced in the previous 12 years since completion of the works. On January 15, 1937, the river at Dayton reached a 14.6 foot stage. The maximum discharge was 53,000 cfs; and it was estimated that a discharge of 90,000 cfs would have occurred without the dams, or about that of the 1898 flood, second only to the 1913 flood among recorded events.

No damage was done to the District works or to the property protected. Without control, the 1937 flood would have caused extensive damage.

The Official Plan of the Miami Conservancy District, once implemented, had indeed provided an almost unequaled degree of flood protection for the citizens of an entire river valley. The demonstrated success of the Miami Conservancy District's Plan, conceived in the aftermath of 1913's devastation, and in place by 1922, became an early model in flood control planning and was studied intensively as the United States began to fully attack its acute flood problems coast to coast and border to border.

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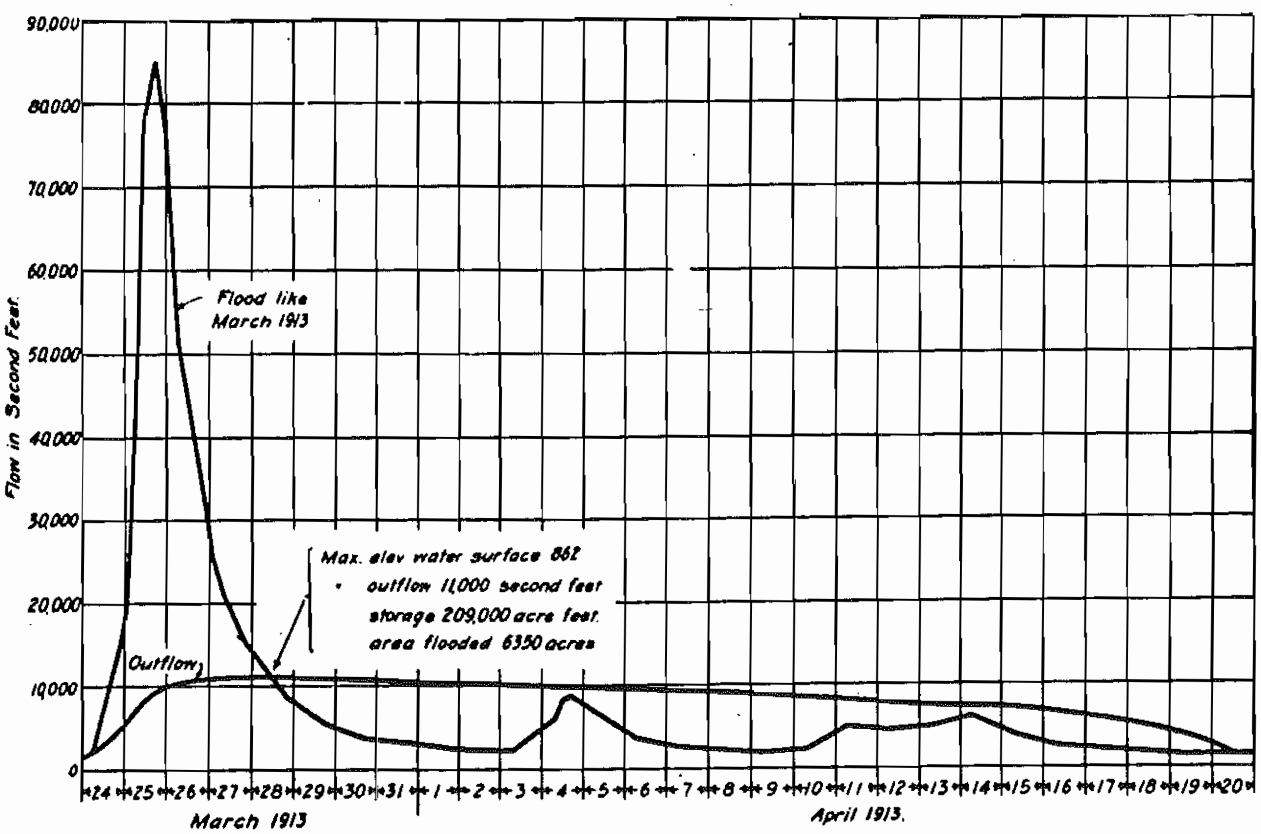
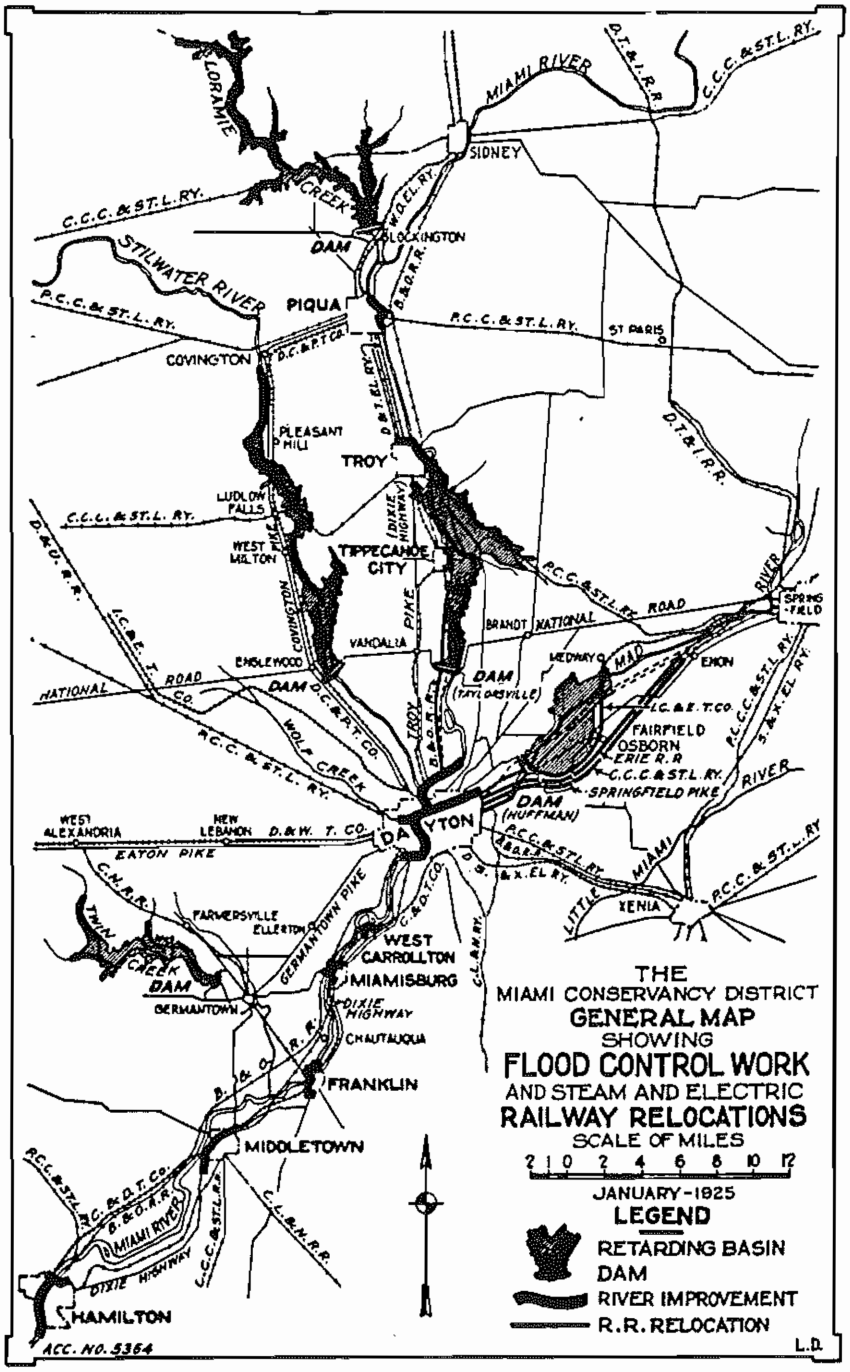


Hydrographs showing size of Flood of March, 1913, at Englewood Retarding Basin, as compared with the rate of outflow from the Basin if it had been in existence.



GENERAL MAP OF THE MIAMI CONSERVANCY DISTRICT

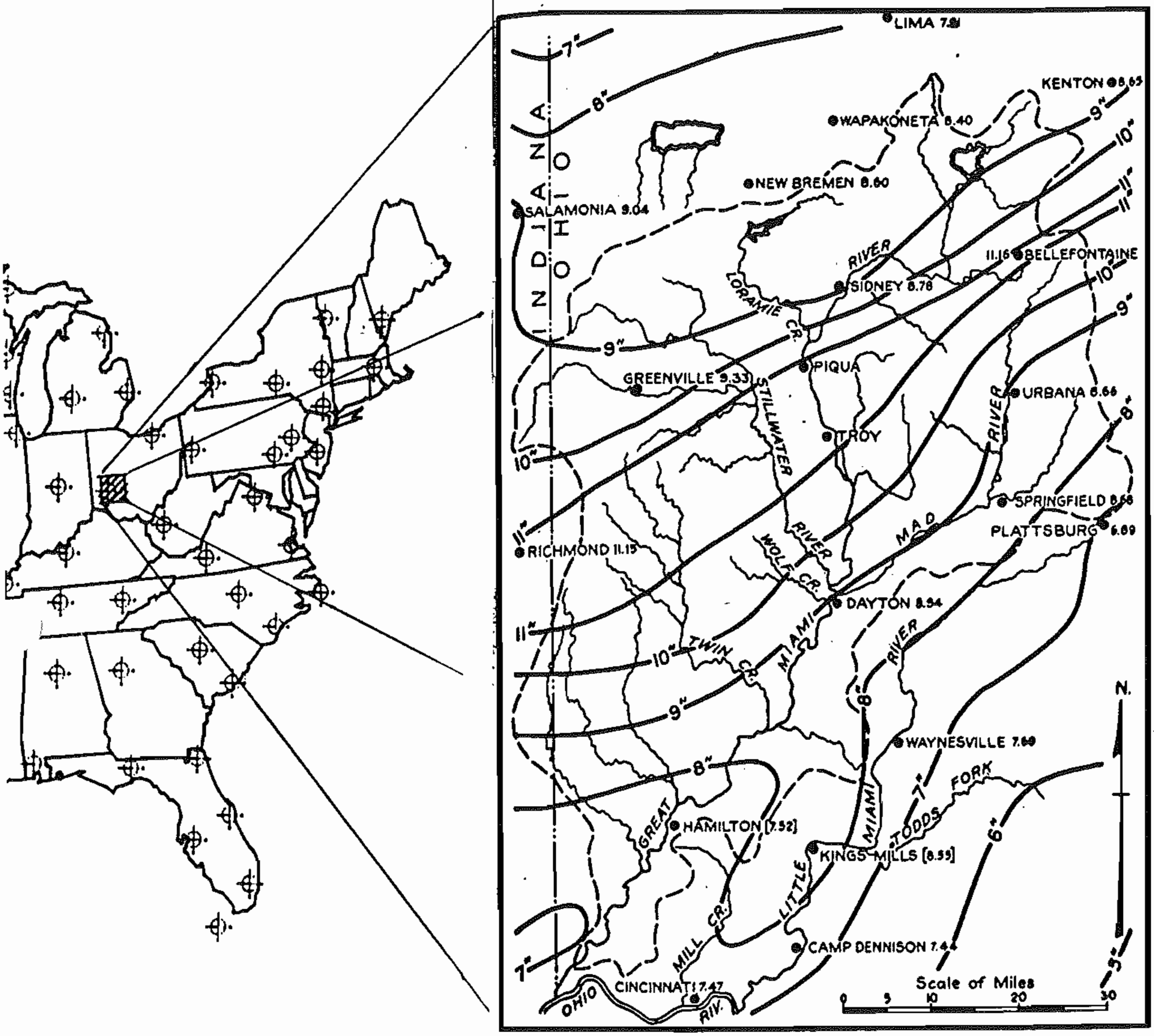
PREVIOUS MAXIMUM GAGE HEIGHTS

Since December, 1892, the U. S. Weather Bureau has recorded daily gage heights of the Miami River at Dayton. From this data a list has been compiled containing all the floods which have reached or exceeded a gage height of 11 feet, during the period from Jan. 1, 1893 to Dec. 31, 1915. Table 7 shows the maximum stages reached; it contains also the heights reached during the floods of 1866 and 1883, based upon the fragmentary records which are available for floods preceding 1893.

Of the twenty-nine floods here recorded, all except five occurred in the winter or early spring, and all except seven of them occurred between the first of January and the end of March.

Table 7.—Maximum River Stages of 11 Feet and Above at Dayton, Ohio. Based on Daily Readings of U. S. Weather Bureau and Fragmentary Early Records. Zero of the River Gage is 733.73 Feet Above Mean Sea Level

Year	Dates of Occurrence												Maximum gage height Feet
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
1866									19				21.3
1883		5											19.0
1893					2								15.8
1897			6										16.3
1898			23										19.7
1903			1										11.8
1904	22												12.5
1904			27										14.8
1904				2									11.2
1905					12								11.0
1906			27										13.2
1907	5												13.8
1907	20												12.5
1907			14										15.2
1908		15											16.1
1908			2										14.3
1908			6										14.4
1908			19										11.0
1909		25											13.8
1910	18												12.6
1910		28											15.7
1910										7			16.1
1912		27											14.5
1912			15										11.2
1912			30										14.2
1913	8												11.0
1913			25										29.0
1913				4									11.6
1915							9						11.3



Cumulated Rainfall map of Miami drainage area for March 23-27, 1913. Rainfall measured at observing stations is shown in inches.

THE GREAT MISSISSIPPI RIVER FLOOD OF 1927

Above normal rainfall from August 1926 through the Spring of 1927 produced the great Mississippi River Flood of 1927. The flood wreaked havoc over much of the 1.25-million-square-mile Mississippi River drainage and was a major milestone in flood control in the United States. The Flood Control Act of May 15, 1928, was enacted as a result of the flood.

Rainfall helping to produce this great event began in the late Summer of 1926 when general rains soaked much of the ground in the Mississippi Basin. In the fall when rainfall and streamflow are normally low, above normal rainfall and higher than normal streamflow occurred. From December 1926 thru April 1927, the mean areal precipitation for the entire Mississippi River drainage was over 12 inches, more than 2 inches above normal. Excessive rainfall over almost the entire basin during the first three weeks of April proved to be a disastrous climax to the rainy period. During the second week of this three-week period, southern Missouri and much of Arkansas received over 9 inches. In 19 hours on April 14-15, the New Orleans vicinity received over 14 inches of rain. The rainfall measured in April 1927 is shown in Figure 1.

The flooding began in the fall when Memphis, Tennessee, reached flood stage and stayed within 5 feet of flood stage until the late Spring 1927. Record and near record flooding occurred in the Cumberland and Tennessee drainages during December. In January, the Ohio River flooded from above normal rainfall and snowmelt from above normal temperatures. The Ohio again flooded in February, as did the Red River. A minor rise in the upper Mississippi flowed past Cairo, Illinois, in March, and all areas of the Mississippi drainage were contributing to a full river channel. The Mississippi had experienced several crests in the fall and winter, with each crest being higher than the previous one. Conditions were set for the most disastrous flooding to follow in April and May.

During the last week in March and the first week in April, the mainstem river points began the rise to their highest crest during the flood. The Mississippi River tributary points at the Ohio River at Cincinnati, Ohio, Cumberland River at Nashville, Tennessee, and Tennessee River at Jacksonville, Tennessee, crested on April 13, 14, and 17, respectively. (Crests at these sites were considerably lower than crests earlier in the year.) On April 20, the Mississippi River at Cairo, Illinois, crested at 56.4 feet. The flood crest moved downstream wreaking havoc as it went. The Mississippi River at Memphis crested at 46.0 feet on April 23. At Vicksburg, Mississippi, the river reached a stage of 58.7 on May 4. The area of inundation during the height of the flood is shown in Figure 2.

While the flood wave was proceeding down the mainstem of the Mississippi, the lower tributaries were experiencing record flooding. On April 21, the Arkansas River at Little Rock, Arkansas, crested at 32.6 feet, the highest level since 1844. The Red River at Shreveport, Louisiana, crested April 30 and at Alexandria, Louisiana, on May 7. These flood waters added to the massive amount of water already flowing down the mainstem of the Mississippi River. The final flood crest passed New Orleans, Louisiana, on May 15 when a stage of 20.7 was measured. It was August before the last of the flood waters flowed into the Gulf.

On April 25, the stage at New Orleans was 21.0 feet, the highest of record. The main flood crest had not reached the city, and it was in danger of being inundated. Experts proposed dynamiting the Caernarvon Levee, 14 miles south of New Orleans, to allow the flood waters to reach the Gulf of Mexico quicker. They expected the stage at New Orleans to drop by 2-3 feet. By order of the Governor of Louisiana, the Caernarvon Levee was dynamited. The stage at New Orleans dropped half a foot, not the 2-3 feet as expected; but the town was saved. Two parishes between the levee and the Gulf were inundated. The final flood crest passed New Orleans on May 15 when a stage of 20.7 feet was recorded.

The levee system to control the Mississippi was decimated with over 120 crevasses or breaks in levees. Water would flow through these breaks inundating towns thought to be protected by the levees and would eventually reenter the Mississippi farther downstream. The crevasses did serve a useful purpose by allowing flood waters to spread out over a larger area, reducing the peak flows along the Mississippi River mainstem. The flood crest at Arkansas City, Arkansas, was at a stage of 60.5 feet, or 2,662,000 cfs flow, was estimated to be reduced by 8.0 feet because of the numerous levee breaks. The crest at New Orleans was estimated to have been reduced by over 6 feet.

Over 16.5 million acres of land in seven states were inundated, and 246 people died. Over 600,000 people were driven from their homes, and damages totalled $230 million. The river was 80 miles wide in some places.

Major changes were planned in the Mississippi River Basin as a result of the flood of 1927. Prior to 1927, there was no comprehensive approach to flood control in the Mississippi drainage. Prior to the flood, $292 million had been spent on piecemeal approach to flood control in the Mississippi drainage. The Corps of Engineers, Mississippi River Commission, and local communities had based their work on controlling the Mississippi River on the popular belief that levees were sufficient to harness flood waters. However, experts could not agree whether levees were sufficient to control the river, or reservoirs should be used to retard the flow from upstream. After the flood and its more than 120 crevasses, people realized that levees alone were insufficient to contain the Mississippi and that a comprehensive and integrated approach to flood control in the Mississippi Basin was required. The Flood Control Act of 1928 was enacted as a result, and $325 million in federal funds were authorized for a comprehensive flood control plan.

The following changes in the Mississippi Valley occurred as a result of the Flood Control Act of 1928:

- The Army Corps of Engineers was given the responsibility and authority for flood control on the Mississippi, replacing the largely piecemeal approach which had previously existed.

- Reservoirs would be built on tributaries to the Mississippi to store and retard the flood waters.

- Levees were designed using engineering principals by the Corps of Engineers and were constructed under their supervision.

- The Mississippi Channel was straightened in places to allow flood waters to escape to the sea faster.

- A floodway was built on the west side of the river near Cairo, Illinois, to divert flood-waters from the main channel. A second set of levees, ten miles outside the main system, was constructed to contain the waters diverted and eventually return them to the main channel.

- A series of river gages was installed and made operational.

- Bonnet Carre Spillway was constructed upstream of New Orleans to divert flood waters from the Mississippi to Lake Ponchartrain to protect the city of New Orleans.

- These measures were completed before the flood of 1937 when the Cairo floodway and the Bonnet Carre spillway were used. The levee system held, even though flows of 1937 exceeded those of 1927.

The great Mississippi Flood of 1927 will be remembered for its severity and destruction and as a major milestone in flood control in the United States with the passage of the Flood Control Act of 1928. The works commenced in the Mississippi River drainage because of the great flood will be felt forever.

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Figure 1. Rainfall for April 1927

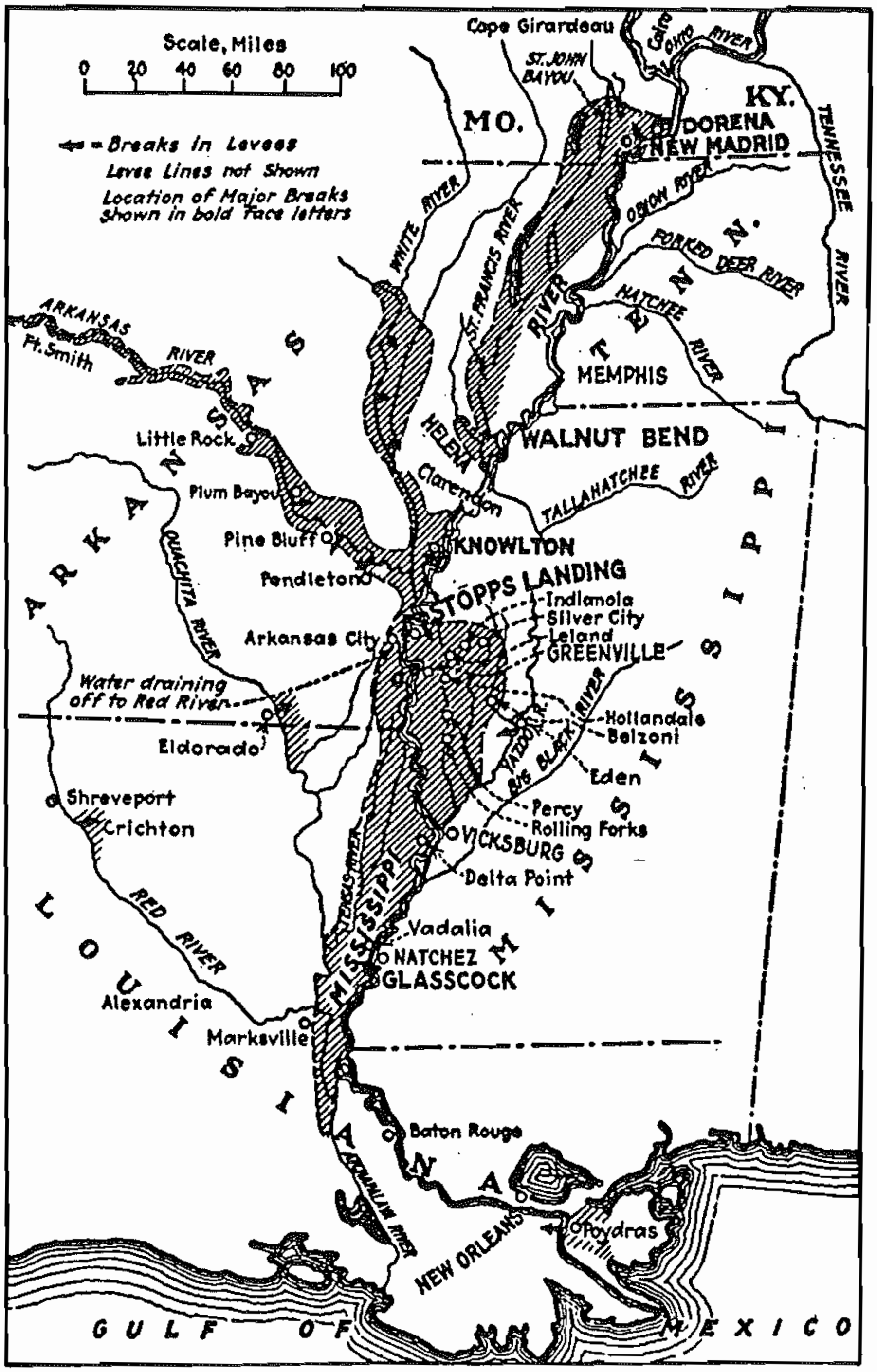

Figure 2. Major levee breaks and areas of inundation on May 4, 1927. Taken from *Engineering News Record*, May 5, 1927.

THE FLOODS IN THE EASTERN UNITED STATES DURING MARCH 1936

Late during the extreme winter of 1935-1936, the rapid melting of the heavy snow pack combined with heavy rainfall to produce major flooding on March 12-13, 1936, in the Northeastern United States and the upper Ohio Valley. A second more damaging flood occurred on March 16-19 when heavy rainfall fell on the still frozen ground in the same areas. Flood levels during this second flood event exceeded many previous records with some over 200 years old. Figure 1 shows the area which experienced the worst flooding.

The winter of 1935-1936 had been extremely harsh. The Monongahela and Allegheny Rivers, which form the Ohio River at Pittsburgh, Pennsylvania, had frozen over with hard clear ice, as had most of the rivers in New England. Over 5 feet of snow were on the ground in the headwaters of the Allegheny, and the snowpack in some areas in New England contained over 6 inches of water equivalent. At the end of February, the ground was frozen through much of the area, and conditions were set for disastrous flooding if abnormal warming should combine with heavy rainfall.

Warm temperatures in the Ohio Valley during the third week of February melted much of the ice in the Ohio River tributaries. The warm temperatures did not reach up into New England, however, and ice on these rivers was still hard. On March 12 and 13, a storm from the Gulf of Mexico brought warm moist air into the Ohio Valley and then into New England. Heavy rain fell, and a substantial portion of the snowpack melted. Pinkham Notch, New Hampshire, received 7.78 inches of rain March 11-13; and over 3 inches of the snow water equivalent melted. On March 17-18, a second storm moved from the Gulf of Mexico into the Ohio Valley and New England. Heavy rain again fell on frozen ground in the area. Pinkham Notch received another 10.76 inches of rainfall , and an additional 4 inches of snow water equivalent melted. In the western portion of New England, sleet fell causing much damage to trees and power lines. Another intense low moved into the area on March 22-23, and the area received heavy rain again. For the period of March 9-21, the heaviest rainfall occurred at Pinkham Notch, where 21.79 inches of rainfall was measured, and an additional 7.5 inches of snow water equivalent melted. Figure 2 shows an isohyetal map of the total rainfall plus water equivalent of melted snow for the Northeast for the period of March 9-21.

Major flooding occurred in New England from water from melting snow and rains March 11-13. Most of the hard ice on the rivers in New England finally broke and dammed up many river valleys making flooding worse. Many structures along the river were damaged by the ice floes. The major river flooding had largely ended on March 16. The flood frequency was estimated to be a one in 25 year event.

During March 19-20, water from melting snow and heavy rains resulted in record and near record flooding from southern Canada southward to Virginia. Even though the hard ice had broken during the March 11-13 event, much of the ice was still in the rivers; and flooding was made worse because of it. The peak flows of almost all major rivers in New England exceeded previous record levels during March 19-20. The Connecticut River at Hartford, Connecticut, with records dating back more than 150 years, exceeded its highest recorded stage by over 9 feet. The Merrimec River at Lowell, Massachusetts, with a period of record of over 200 years, exceeded its previous peak flow by over 65 percent! The Kennebec River at Waterville, Maine, exceeded all flood marks on "Freshet Oak," a landmark of floods since 1836.

The Susquehanna River in eastern Pennsylvania was hit extremely hard. In the Juanita and West Branch, flash flooding was very damaging. Flood crests from the Juanita, North Branch Susquehanna, and West Branch synchronized at Harrisburg to produce a foot crest with a peak stage of 30.4 feet, exceeding the previous record stage set in 1889 by 3.3 feet. In parts of the city, water was up to second story windows.

Record flooding occurred on the Monongahela, Allegheny, Conemaugh, and Ohio Rivers. Flooding occurred on many of the minor tributaries, but flooding on these tributaries was not as damaging as the flooding on the mainstem of the rivers. In the mountains of West Virginia and Pennsylvania, flash flooding was severe. At Johnstown on the Conemaugh, the flood was only 1.5 feet below the flood of the 1889 dambreak, and the speed and intensity of the flooding was comparable to the 1889 flood. Downstream at Pittsburgh where the Monongahela and Allegheny meet to form the Ohio, the 46-foot stage on March 18 exceeded previous records and inundated over 60 percent of the "Golden Triangle." Downstream at Wheeling, West Virginia, the 55.5 foot crest exceeded the previous record set in 1884 by more then 2 feet.

A third flood peak, lower than the peak of March 19-20, occurred on March 22-23. This ended the most tragic flooding of the Ohio River and rivers in the Northeast since records were begun.

The flood waters caused over $270 million in damages, including over $200 million in Pittsburgh. The death toll was 107, and many people were forced to evacuate their homes.

Two months after the flooding occurred, the Flood Control Act of 1936 was enacted. This act, representing national stream planning on a large scale, authorized $310 million for flood control. A large portion of this money was used to construct reservoirs in the Ohio drainage to protect Pittsburgh and the other communities downstream. An analysis showed that these reservoirs would have reduced the flood crest by over 7 feet in Pittsburgh.

The Weather Bureau received many complaints for not warning people of the impending flood. There were few snow depth observations, and no reports of snow water equivalent on the ground were available. Communications failed, and weather offices were able to obtain only a few river and rainfall reports. Officials estimated that accurate flood warnings could have saved $100 million of the damages in Pittsburgh and began to realize the importance of good precipitation and snow observations in increasing the lead time of flood forecasts.

Perhaps significantly, the nation began to realize the importance of the flood forecast services and called for the government to take a more active role in this area. Partially as a result of the flooding, the Weather Bureau embarked on a plan to divide the country into areas where river districts would specialize in river forecasting. In 1937, small staffs were placed in the Weather Bureau offices in the Missouri Valley and the Upper Mississippi Valley to specialize in river and flood forecasting. These were the forerunners of National Weather Service's River Forecast Centers as we now know them.

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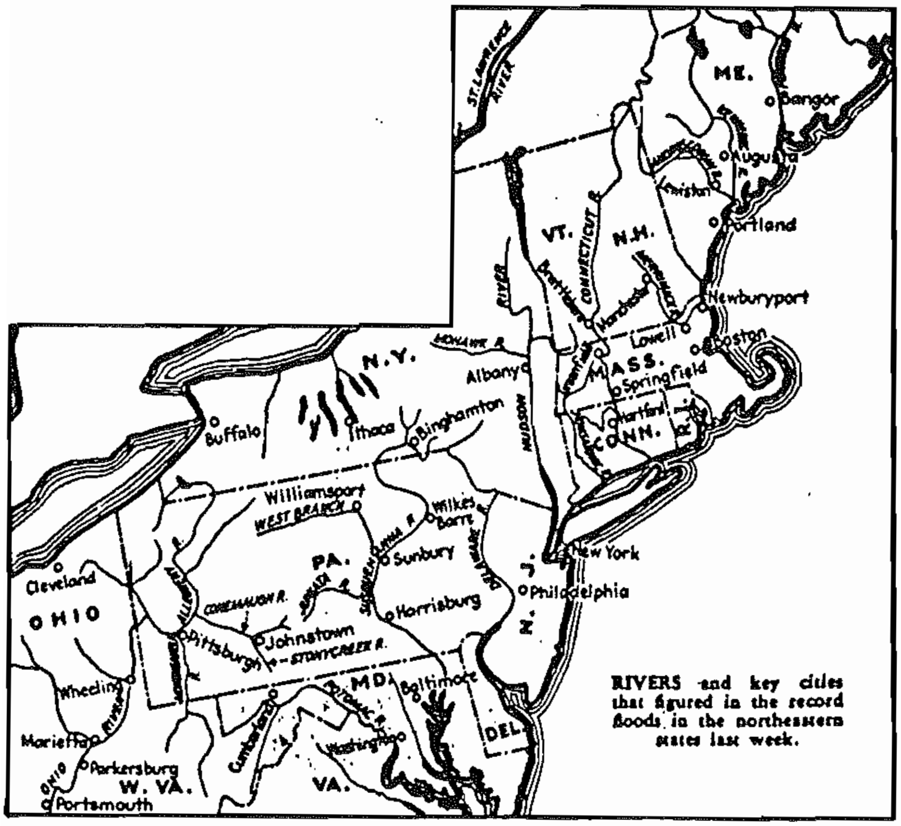

Figure 1. Area of flooding during March 1936

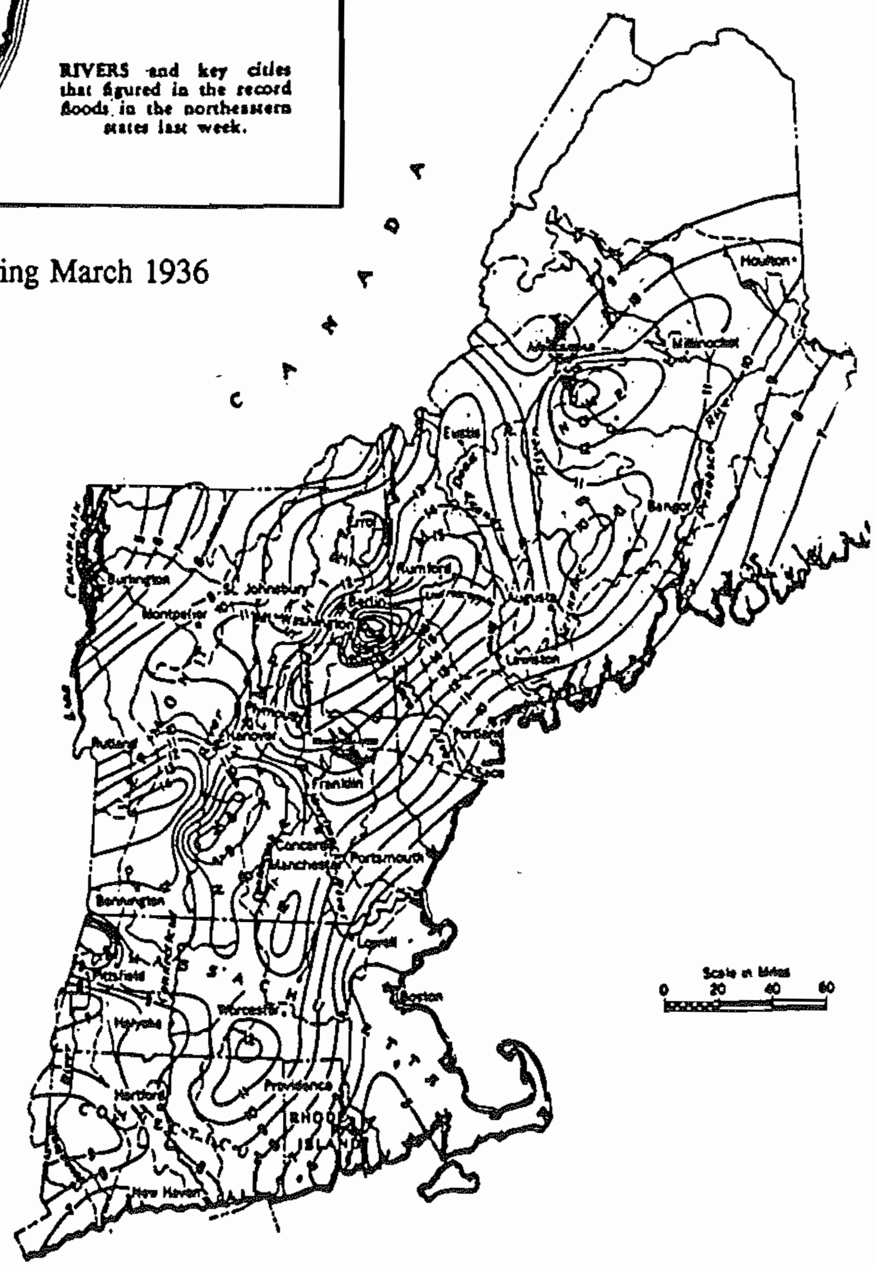

Figure 2. Total rainfall plus water equivalent of melted snow for March 9-21, 193

THE OHIO RIVER FLOOD OF JANUARY 1937

**** *Conditions on this river are simply hell. The people simply refuse to evacuate ahead of the time of serious danger, and then the rescue load comes all at once. The army engineers stepped into this strange job of rescue and evacuation in great style. They are doing all that is humanly possible to bring order out of chaos. I have seen it happen right here today.*

Report filed by H. W. Richardson, Associate Editor, *Engineering News-Record*, February 4, 1937 ****

DECEMBER PRESAGED JANUARY'S DISASTER

The great flood of January - February 1937 in the Ohio Valley had its beginning in the latter part of December 1936 when moderate to heavy rains began over the entire Ohio River watershed. A general rise began in the lower portion of the river during the last week of December 1936 and developed within one month's time into the greatest flood of record on that river.

JANUARY RAINS UNPRECEDENTED

The flood resulted from excessive rains which followed during the month of January. There was practically no snow on the ground at the beginning of the month, and whatever small amounts fell subsequently were absorbed in the general rains and had no appreciable effect on the flood. The greatest concentration of rainfall occurred in the lower portions of the Ohio Valley, with the month's totals in this area being more than four times the normal amount for January. Practically all the precipitation that occurred over the Ohio Valley during January occurred within the period from the 1st to the 24th, inclusive. Especially during the period 13th-24th, the rainfall was exceedingly heavy (see Figure 2); and the greatest intensity was located along the Ohio River from Cincinnati, Ohio, to the mouth. The axis of this area followed the Ohio River from Cincinnati to Louisville, Kentucky; and from there, it lay a very short distance south of the course of the main stream.

By the morning of the 18th, the Ohio River was in flood from the mouth upstream to Cincinnati. Heavy excessive rains which had begun on the 17th continued almost without exception until the morning of the 25th. The area of heaviest precipitation wavered back and forth across the Ohio River, and it was seldom during this period that the precipitation area moved far enough from the river that the downpours did not affect it. It was eventually determined that precipitation of 16 inches or more had occurred over two areas of 10,000 square miles each, and of 12 inches or more over an area of about 100,000 square miles.

This 1937 flood surpassed all previous floods during 175 years of civilized occupancy of the lower valley. The previous great flood occurred in 1884 at Louisville, and an earlier monstrous flood had occurred in 1773. Nonetheless, even geologic evidence suggests that in lower parts of the valley, this 1937 flood exceeded **any** previous flood.

The runoff from heavy rains falling in such close proximity to the Ohio River passed quickly into the main stream which was already full, and resulted in a rapid rise over a long reach in the river; and by the morning of the 24th, which was probably the darkest moment in the history of the flood, the entire Ohio River was above flood stage, and all records had been broken from Cairo, Illinois, to Portsmouth, Ohio. The greatest 24-hour rise from 7 AM to 7 AM occurred after exceptionally heavy rains on the 20th-21st when the water rose 6.7 feet at Cincinnati (see Figure 3) and 6.3 feet at Louisville. On the morning of the 24th occurred the final downpour of the flood. The effective rains of the flood ended shortly after this period, and within a day or two the river crested at most points along the river, except at the lower portion.

All previous records were broken along the Ohio River from slightly below Point Pleasant, West Virginia, to the mouth at Cairo, Illinois. At Cincinnati, with a stage of 80 feet on January 26, the flood stage was exceeded by 28 feet; and the previous highest stage there, 71.1 feet in 1884, was exceeded by 8.9 feet. The height of the flood was greatest in the Louisville district, where stages were about 30 feet above flood stage and more than 11 feet above the previous highest stages of record. At Cairo, Illinois, the crest reached was 19.6 feet above flood stage and 3.2 feet above the highest stage previously recorded there.

EVACUATION, LOSSES TREMENDOUS

The loss and damage that occurred in the Ohio Valley from this flood was tremendous. The hardest hit of the larger cities was Louisville, where nearly 70 per cent of the city was under water, and about 175,000 people were forced to vacate their homes. Cincinnati, because of its higher elevation, was fortunate in that only 10 percent of its area was covered by water. However, the city was practically paralyzed by loss of water, power, heat, and light, and nearly helpless to combat fires that broke out. A number of smaller cities along the lower Ohio River were completely submerged. The whole city of Paducah, Kentucky, with a population of about 35,000, was evacuated. Jeffersonville, Indiana, across the river from Louisville, was 90% inundated; and 13,000 people fled their homes, while in the Evansville, Indiana, area, about 90,000 people were forced to flee their homes. Many smaller towns actually suffered more than the larger ones. Brookport, Illinois, for one, was completely inundated.

The city of Portsmouth, Ohio, was supposedly protected by a famous 60-foot wall, which had safely withheld the flood of March 1936, just ten months earlier. However, in this 1937 flood, the height of the water exceeded the top of the wall by more than 14 feet. As soon as it became apparent that the river stage would exceed the top of the wall, action was taken to permit the water to enter the city through wall openings in order to minimize the force of the current flowing over the wall. However, the rise of the river was so rapid that this action was only partially successful, and considerable damage occurred from water rushing over the wall. The first flow of water over the wall created a fearful raging torrent through the hapless town's streets. Overall, Portsmouth's physical damage was probably the greatest in the valley.

Cairo, Illinois, on the other hand, was safe behind its 60-foot wall as the crest of the river went up to 59.6 feet, a rise to a mere 0.4 foot below the wall's top!

MISSISSIPPI VALLEY SPARED

The February 4, 1937, *Engineering News-Record* ran the following headline and remark:

> *FLOOD PLAN TESTED - The costly plans for control of floods in the lower Mississippi River Valley, begun after the 1927 flood, are being tested by a flood greater than that of 1927. How well the strengthened levee system, cutoffs and floodways will function is of great interest to engineers concerned with river control.*

Thanks in part to the prolonged rains that caused the flood, the flood crest out of the Ohio River, entering the Mississippi River at Cairo, was one of unusual flatness, or length of crest. That may have helped in "breaking in" the new floodway system of the Mississippi. At any rate, downstream along the Mississippi River, damage was confined almost entirely to the overflow between the banks and the levees and in the backwater areas of the tributaries. The Mississippi levee system, improved and constructed after the disastrous flood of 1927, withstood the exceptionally high stages remarkably well; and no prominent levee breaks occurred.

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FLOOD STAGES -- OHIO RIVER -- JANUARY, FEBRUARY 1937

Station	Flood Stage	Above Flood Stage			Crest	
		From	To	Days	Stage	Date
Portsmouth, OH	50 ft	Jan 18	Feb 3	17	74.1	Jan 27
Cincinnati, OH	52 ft	Jan 18	Feb 5	19	80.0	Jan 26
Louisville, KY	51 ft	Jan 16	Feb 7	23	81.4	Jan 27
Evansville, IN	35 ft	Jan 10	Feb 19	40	53.8	Jan 31
Paducah, KY	39 ft	Jan 10	Feb 22	43	60.6	Feb 2
Cairo, IL	40 ft	Jan 9	Feb 27	49	59.6	Feb 3,4

COMPARISONS TO PREVIOUS RECORD FLOODS

Station	1937		Previous Year	Record Stage
	Stage	Discharge		
Portsmouth, OH	74.1		1913	67.9
Cincinnati, OH	80.0	950,000 cfs	1884	71.1
Louisville, KY	81.4	1,100,000 cfs	1884	70.0
Evansville, IN	53.8		1884	40.4
Paducah, KY	60.6	1,980,000 cfs	1913	54.3
Cairo, IL	59.6		1927	56.9

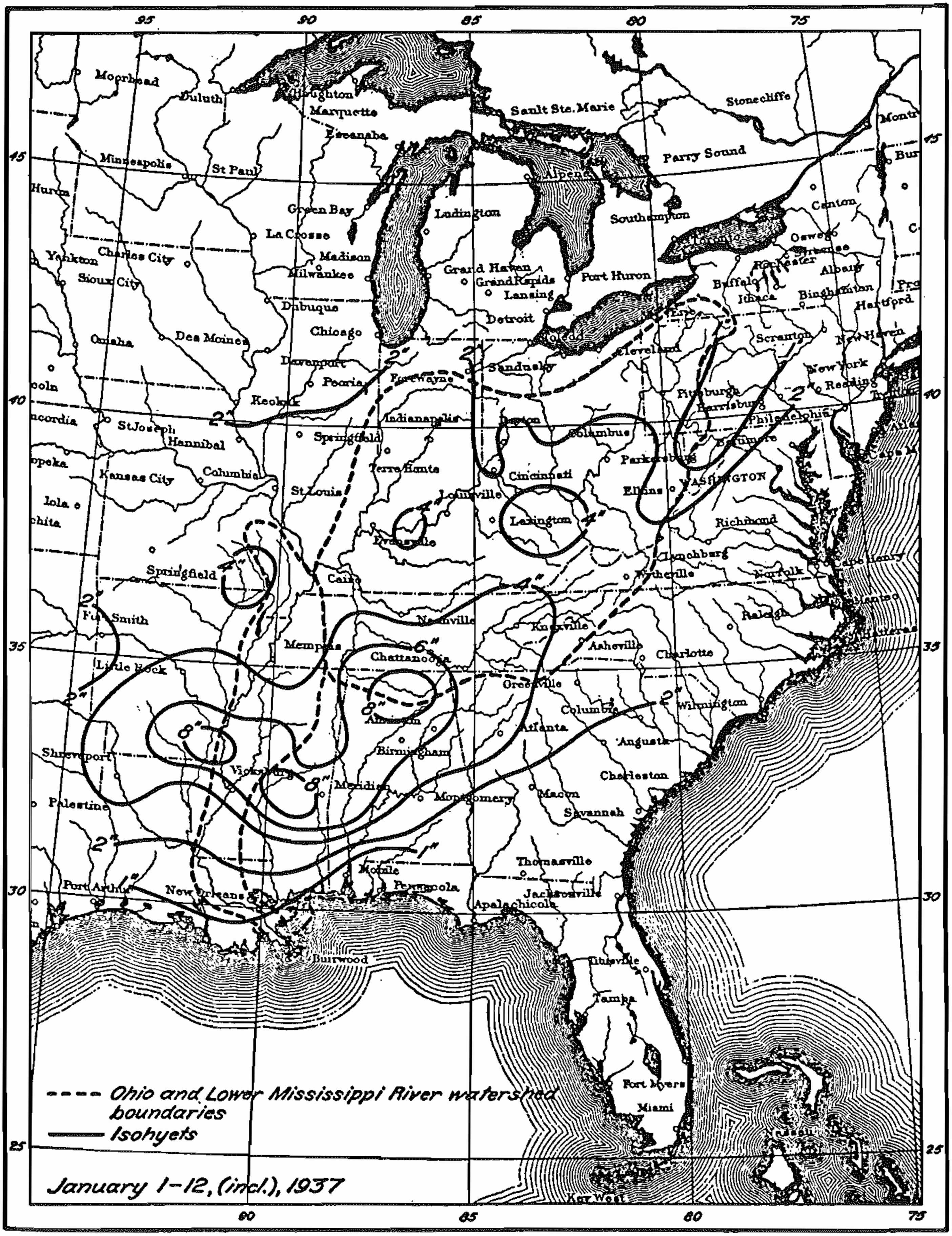

Figure 1. Precipitation for January 1-12, inclusive, 1937.

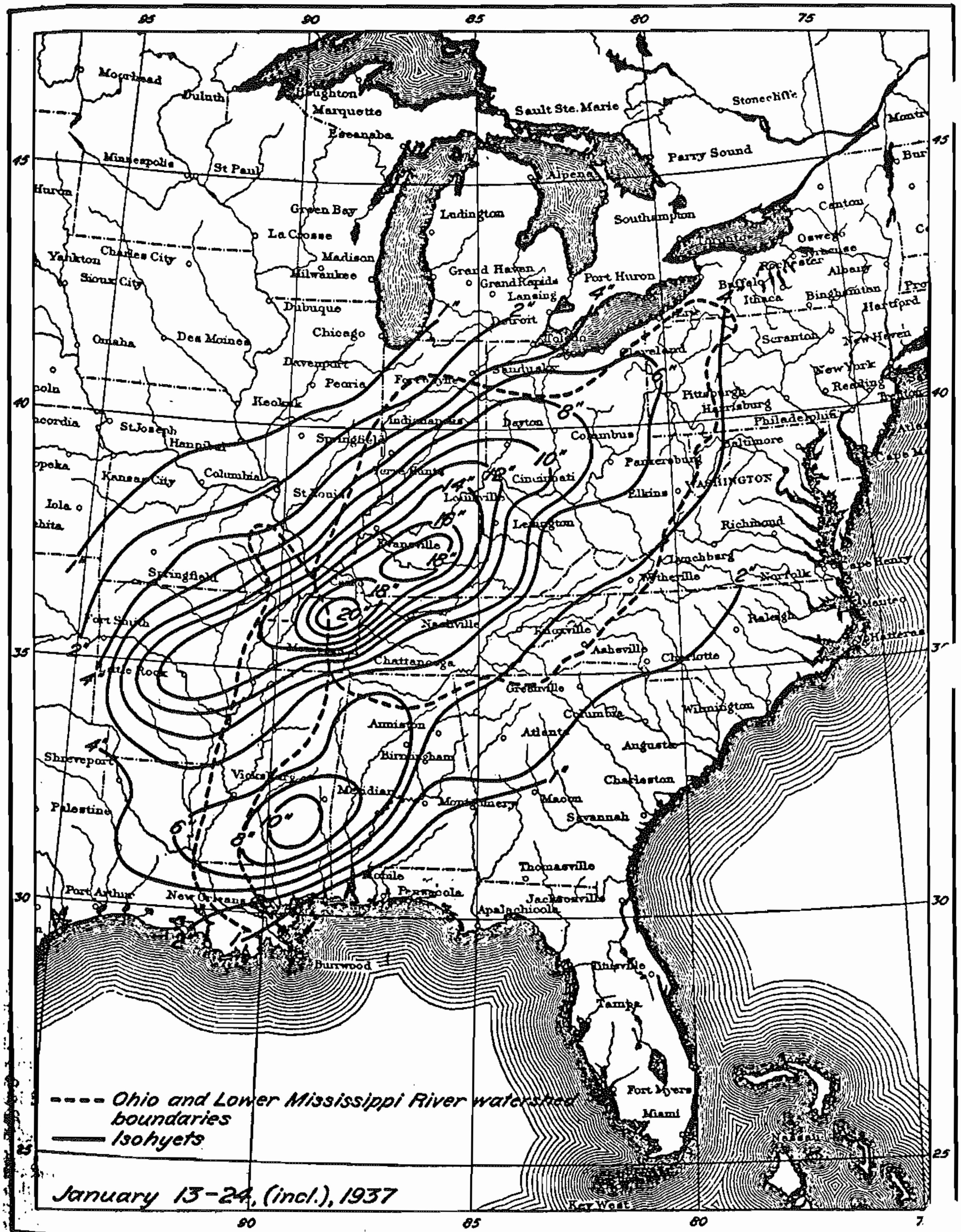

Figure 2. Precipitation for January 13-24, inclusive, 1937.

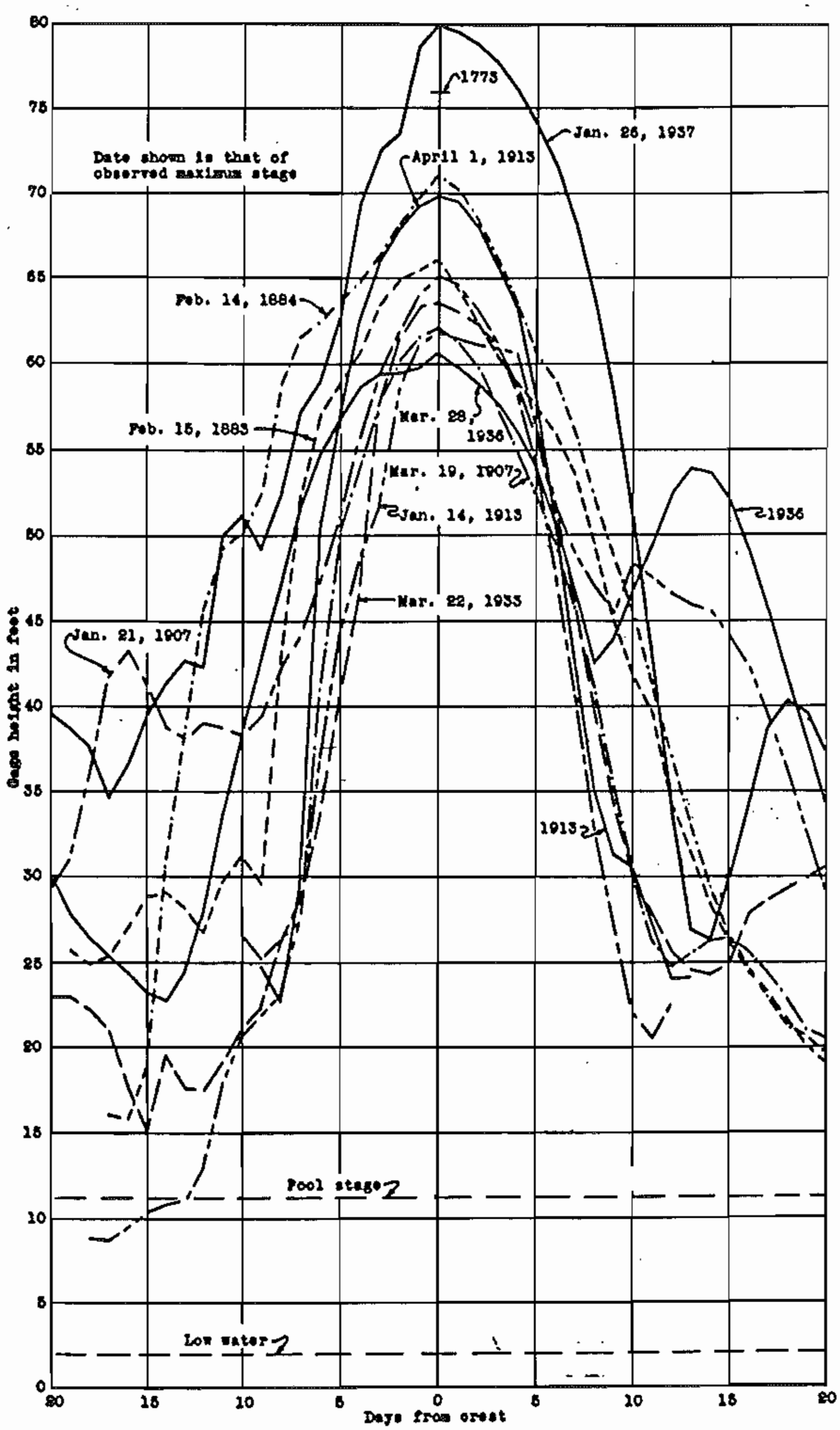

Figure 3. Hydrographs of the Ohio River at Cincinnati, Ohio, showing stages reached by the flood of January-February 1937 and selected previous floods.

THE KANSAS-MISSOURI FLOODS OF JUNE-JULY 1951

Devastating floods occurred in eastern Kansas and Missouri during the spring and early summer of 1951. After three months of above normal precipitation, storms on July 9-13 produced the most destructive flooding in over 100 years in the Kansas River, the lower Missouri River, the Mississippi River below Saint Louis, the Marias des Cygnes River, and the Neosho River.

The spring of 1951 had been abnormally wet and cool. During June and the first half of July, a north-south oriented ridge of high pressure persisted in the Gulf of Alaska; and a trough of low pressure persisted from south central Canada to the southwestern U.S. This pattern brought unusually cold air to the northern Rockies and Great Plains states. In Kansas, these cold air masses made contact with warm moist air from the Gulf of Mexico producing thunderstorms and much above normal rainfall. After the storms of July 9-13 produced up to 17 inches of rain, a ridge formed over the Central Plains, and the heavy rains stopped.

Large portions of Kansas and Nebraska received over 200 per cent of normal rainfall in April and May. The June average rainfall over Kansas was 9.69 inches, almost six inches above normal, and two inches above the previous record monthly average. Table 1 shows May through July rainfall totals. During the first eight days of July, intermittent light rain fell in Kansas, just prior to an outbreak of very heavy rains. Rainfall around Manhattan, Kansas, totalled four to five inches on the night of July 9-10, and five to seven inches on the 11th. Shown in Figure 1, the four-day storm totals on July 9-13 neared 17 inches in parts of the state, and resulted in floods which provided a devastating climax to more than three months of unusually rainy weather.

Severe flooding occurred in June, but flooding in July was worse. July runoff volumes in the Kansas and Neosho Basins doubled their average yearly values. Friday, July 13, 1951, was truly a "Friday the Thirteenth," and has been described as the single greatest day of flood destruction in Midwestern United States history, when a record flood crest on the Kansas River moved from Manhattan to Bonner Springs. The Kansas River at Kansas City crested early on the morning of July 14. Later that morning, the flood waters spilled into the Missouri, and a crest 14 feet above flood stage was measured. The peak flow there was 573,000 cfs. The flood crest continued down the Missouri and reached Saint Louis on July 22. Flood crests exceeded all previously known flood levels on the Kansas and lower Missouri since records began. (However, the flood crests were about one or two feet below the high water marks from a monster flood of 1844.)

These destructive floods inundated over 5000 square miles and caused almost $1 billion in damage, half of which occurred in the Kansas City metropolitan area. Twenty-eight lives were lost. Water levels reached the second story in buildings in Topeka and Kansas City. Over 150 communities, including the state capitals of Topeka and Jefferson City, were devastated. Over 500,000 people were displaced from their homes.

In 1951, no more than five federal flood control dams regulated 11,500 square miles of the 60,060-square-mile Kansas River Basin. With only 800,000 acre-feet of flood storage, they offered insufficient protection from the tremendous volume of floodwater developed by the season's copious rains. Many other reservoirs authorized by the Flood Control Act of 1944 were in stages of planning, however, by the Corps of Engineers and Bureau of Reclamation. This flooding heightened interest in flood control, and funds became available to complete many projects. Today, 18 reservoirs help regulate flow in the Kansas River Basin. In addition, more levees, flood walls, and channel improvements have given cities additional protection from flooding.

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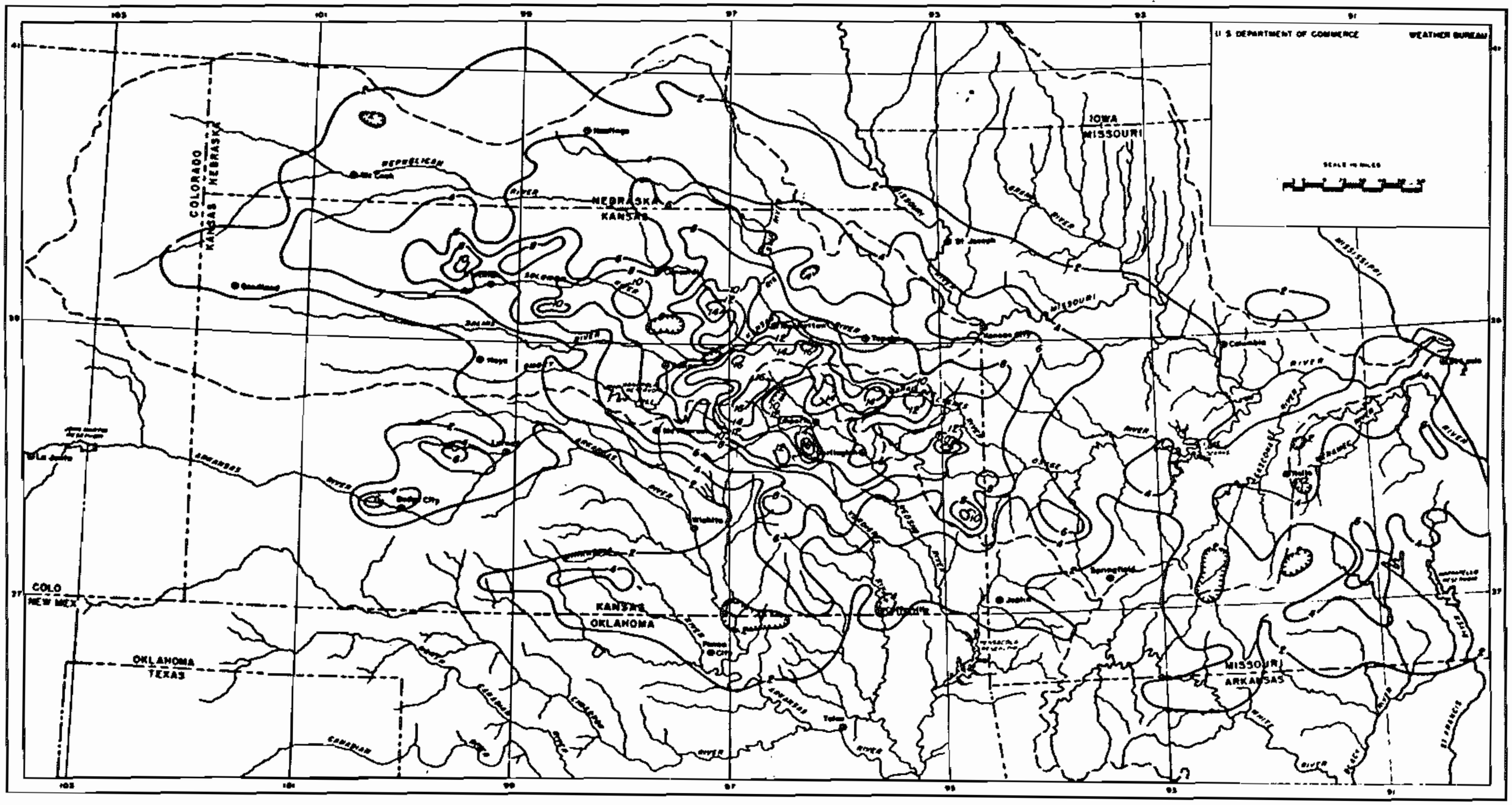

*Figure 1. Total precipitation for storm of July 9-13, 1951.

*Taken from: *Kansas-Missouri Floods of June-July 1951*, U.S. Department of Commerce Weather Bureau Technical Paper No. 17.

*Table 1

SUMMARY OF MAY-JULY, 1951 PRECIPITATION IN KANSAS
(Normal, observed, and departure from normal, in inches, shown in monthly columns)

State Division	May Nor.	May Obs.	May Dep.	June Nor.	June Obs.	June Dep.	July Nor.	July Obs.	July Dep.	Accumulated May-July Nor.	Accumulated May-July Obs.	Accumulated May-July Dep.
Northwest	2.69	4.50	+1.81	2.96	6.70	+3.74	2.73	5.36	+2.63	8.38	16.56	+8.18
N. Central	3.63	5.12	+1.49	4.11	11.42	+7.31	2.93	8.00	+5.07	10.67	24.54	+13.87
Northeast	4.37	6.69	+2.32	4.60	12.37	+7.77	3.34	9.36	+6.02	12.31	28.42	+16.11
W. Central	2.79	5.32	+2.53	3.07	10.82	+7.75	2.58	3.02	+0.44	8.44	19.16	+10.72
Central	3.87	6.69	+2.82	4.25	9.52	+5.27	2.77	7.64	+4.87	10.89	23.85	+12.96
E. Central	4.81	6.88	+2.07	4.74	9.74	+5.00	3.46	13.07	+9.61	13.01	29.69	+16.68
Southwest	2.74	6.88	+4.14	2.85	6.16	+3.31	2.49	3.80	+1.31	8.08	16.84	+8.76
S. Central	4.13	8.28	+4.15	4.10	8.75	+4.65	2.86	4.32	+1.46	11.09	21.35	+10.26
Southeast	4.90	6.59	+1.69	5.19	12.02	+6.83	3.51	6.67	+3.16	13.60	25.28	+11.68
State Avg.	3.77	6.43	+2.66	3.97	9.55	+5.58	2.95	6.60	+3.65	10.69	22.58	+11.89

*Taken from: "Kansas-Missouri Floods of June-July 1951,"
U.S. Department of Commerce Weather Bureau Technical Paper No. 17

FLOODS IN THE UPPER MISSISSIPPI AND MISSOURI RIVERS AND RED RIVER OF THE NORTH DURING THE SPRING 1952

During April 1952, devastating floods occurred along the Upper Mississippi and Missouri Rivers and Red River of the North when a sudden warming trend following a bitterly cold winter melted the heavy snowpack. Significant precipitation did not accompany the warming. Water solely from the rapidly melting heavy snowpack produced record and near record flooding over 3000 miles of mainstem channels and over 2000 miles of tributaries as shown in Figure 1. As you shall see, the warnings of the Weather Bureau played a vital role in helping to reduce damages during this storm.

The stage for this 1952 flood was actually set during the preceding year's winter and summer. During the winter of 1950-1951, the northern Great Plains received above average snowfall. In the same area, summer and fall of 1951 were cooler and wetter than normal; and the soil was left extremely moist. In November 1951, the wet ground froze from temperatures 2-8°F below normal when the region plunged into winter. The extreme cold during the ensuing months produced frost depths from 18-80 inches, with most between 24 and 42 inches, substantially deeper then normal. At the end of March 1952, eastern Montana, the Dakotas, Minnesota, and Wisconsin had unusually heavy snowpacks with over 6 inches of water equivalent in some areas. Despite high flows in the rivers during the winter, the ice cover on the rivers was abnormally thick and solid. The conditions were ripe for a major flooding event in the Missouri and Upper Mississippi Rivers and Red River of the North during late March and April if sudden warming occurred.

In the Upper Mississippi, the first of two warming spells occurred from March 29 through April 1, affecting mostly the southern part of the basin. Record flooding occurred along the Cannon and Root Rivers in southern Minnesota. Many small tributaries in the area had sharp rises. All of this flood flow combined for a minor flood crest on the Mississippi River at La Crosse, Wisconsin, on April 4. The second warm spell saw temperatures reach as high as 60°F in a band across central Minnesota when an intense and abrupt warming occurred April 6-9. The Rum River, Crow River, and numerous tributaries in central Minnesota reached record levels on April 13. A near record crest on the Minnesota River passed Mankato, Minnesota, on April 14. The flows in the upper tributaries of the Mississippi synchronized with flood flow in the Minnesota for a 22.1-feet crest on the Mississippi at St. Paul, Minnesota, the highest since records began in 1867. As the flood wave moved down the Mississippi mainstem, record and near record flooding occurred all the way to the confluence with the Missouri.

The ice on the rivers in the Missouri Basin was 32 inches thick in some areas, a thickness seldom achieved. In late March, the first temperatures warm enough to melt snow occurred in the northwestern most headwaters of the Missouri in the Milk and Yellowstone Rivers. This contrasts with the normal ice breakup which proceeds upstream from the south and east. Flood waters from the Yellowstone River piled up against the frozen Missouri mainstem and finally broke through, producing a near record flood crest at Williston, North Dakota, on April 1. As the flood waters fought to break the ice damming up the Missouri, waters from the Little

Missouri added to the crest. At the same time, a rapid thaw was progressing upstream from the south. On April 8 when an ice dam above Bismarck, North Dakota, broke, the flood waters from upstream and the thaw from downstream finally met south of Bismarck. That same day, Bismarck recorded its third highest stage of record. The crest reached record levels at Sioux City, Iowa, on April 14 and then Omaha, Nebraska, on April 18. By the time the flood wave reached Kansas City on April 24, it had attenuated below record levels.

The flooding was worsened by the tremendous ice jams in the Missouri River. One of the most awesome occurrences was at Bismarck. On April 8 at 10 AM, the discharge at Bismarck was 75,000 cfs at a stage of 19 feet. Later that day, a large ice dam upstream from Bismarck broke, and the discharge rose to 500,000 cfs by 6 PM that evening as shown in Figure 2. The peak flow at Bismarck as a result of the ice jam breakage was more than 65 per cent of the total of all peak discharges observed in the tributaries upstream.

Because of a lighter snowpack than in the Mississippi and Missouri drainage, the flooding was not as severe in the Red River of the North, an international river that flows northward from the United States into Canada. Some upstream (southern) tributaries had record flooding from the heavy snowpack and the water being dammed by ice. Since the heavy snowpack was confined to only a few basins and the ice in the river was not as thick as the Missouri, the flood wave from these tributaries was attenuated significantly, and the flooding was much less severe downstream, to the north, on the mainstem.

Damages from the flooding totalled $200 million with $118 million of that to crops and agriculture. Eleven lives were lost. Over 3 million acres were inundated, and almost every major population center in the upper mid-west was affected by the flooding. Fort Pierre, South Dakota, was 85 per cent inundated; 75 per cent of South Sioux City, Iowa, was inundated, and 15,000 people were homeless. In South Dakota, between 30,000 and 40,000 people were driven from their homes due to the flood waters. In total, some 200 municipalities of all sizes suffered some degree of flooding.

Advance warnings of the impending floods issued by the Weather Bureau were instrumental in spurring damage-reducing activities in many instances. The Weather Bureau issued a general news release warning people of possible serious flooding on the Missouri River on February 29, almost a month before the flooding began. A second bulletin was issued on March 13. The flood warnings are credited with saving $102 million. Because of the advanced warning, levees were strengthened or raised in preparation for the flood. The Corps of Engineers estimated that construction work in the form of protective structures prevented damages of $238 million. Coordinated efforts by all levels of government and welfare facilities costing a total of $13.5 million resulted in total savings of over $400 million, far surpassing the $200 million in damages which occurred.

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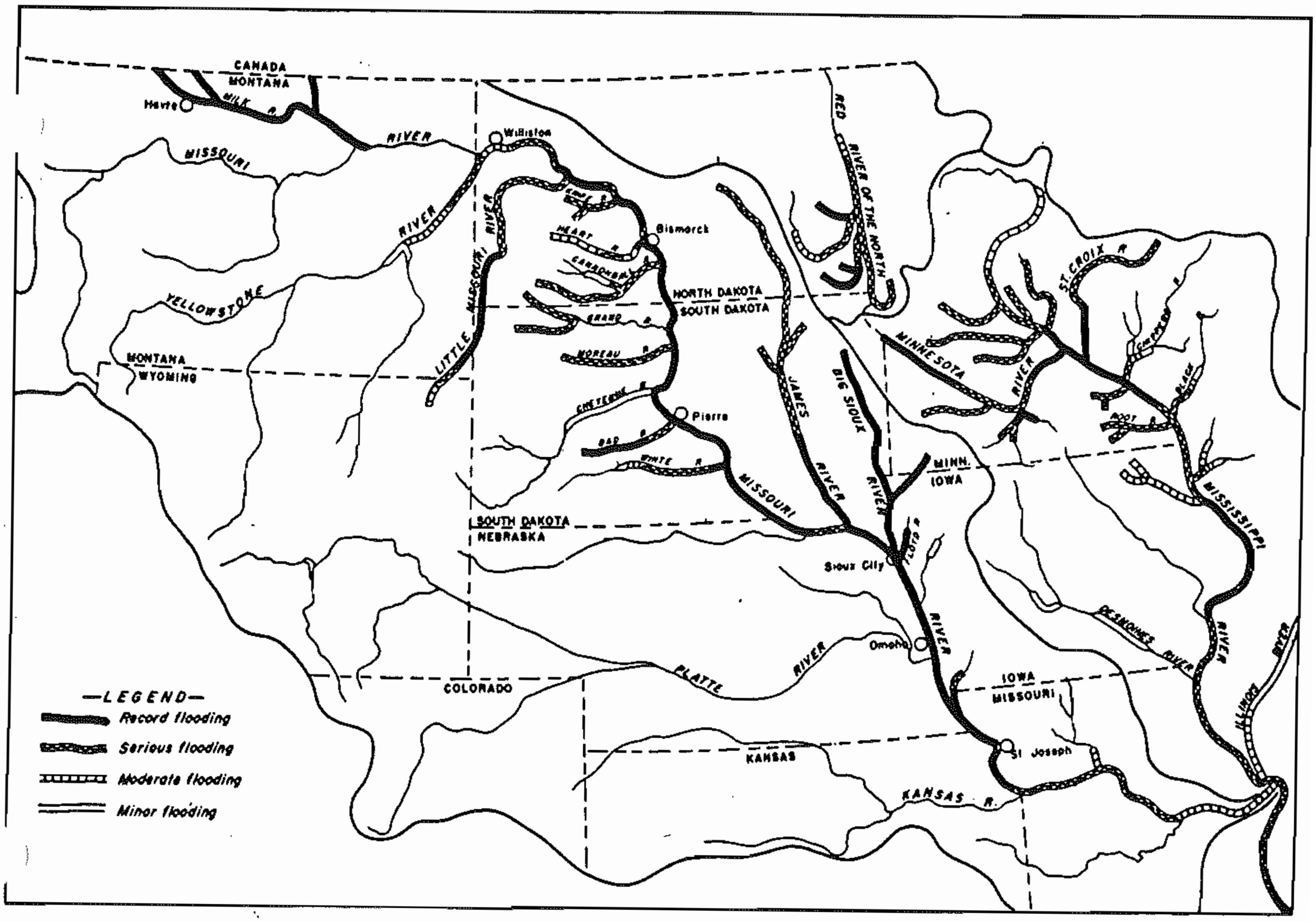

Figure 1. Map showing flood conditions April-May 1952

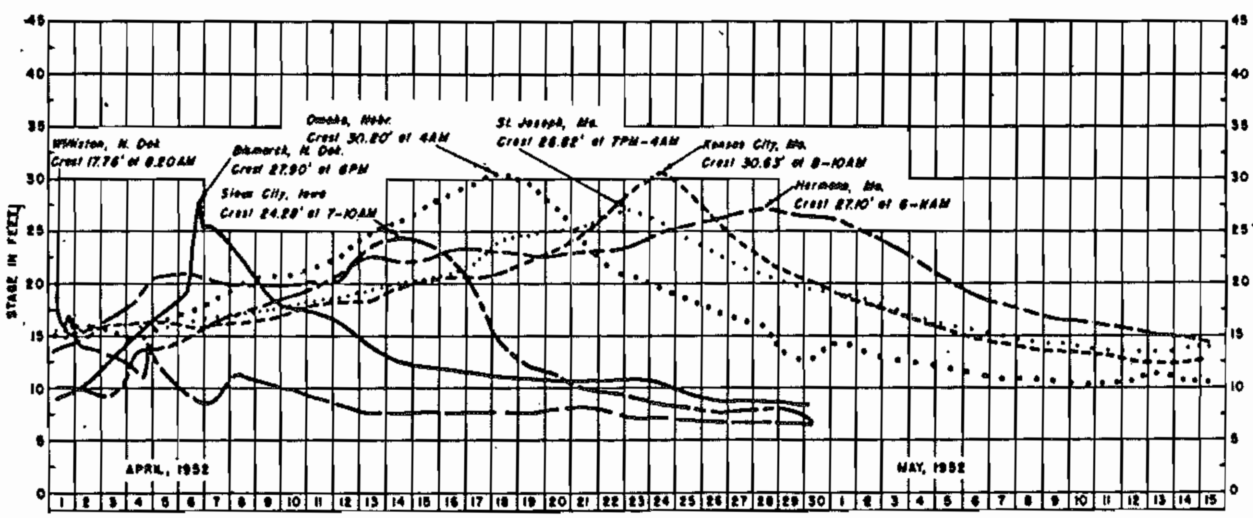

Figure 2. River stage graphs, Missouri River

THE JUNE 1954 FLOOD ON THE INTERNATIONAL RIVER, THE RIO GRANDE, BETWEEN TEXAS AND MEXICO

MASSIVE FLOOD DISCHARGES

The first permanent settlement on the lower Rio Grande, the international boundary between the United States and Mexico, between present-day Del Rio, Texas, and the river's mouth at the Gulf of Mexico, was founded in 1746. It has been well established that on the remote 300 river mile reach of the Rio Grande from Del Rio to Rio Grande City, Texas, the greatest flood for which there is any written or traditional record since 1746 occurred in June 1865 (1). Unfortunately, not a great deal is known about that 1865 flood.

The second greatest Rio Grande flood in this reach occurred in 1954. The record-breaking rainfall causing this flood was associated with Hurricane Alice, which crossed the coast from the Gulf of Mexico 50 miles south of Brownsville on June 24-25, 1954 (4). The heaviest rainfall was on the Pecos River below Sheffield and on its tributary, Howards Creek, and on the Devils River's tributary, Johnson Draw. On this Draw the town of Ozona was badly flooded, and several persons drowned. Rainfalls up to 35 inches were observed at two centers 22 miles and 40 miles northward from Langtry. Langtry lies on the Rio Grande several hundred miles inland from the Gulf. Figure 1 shows the isohyetal pattern of the rainfall.

From recorded stages, it has been estimated that the Pecos River at Comstock, Texas, passed 948,000 cubic feet per second (cfs) of flood water on June 28, 1954. It has also been deduced that a flood crest of 1,140,000 cfs passed Del Rio, Texas, on the Rio Grande that same day. Those and other astounding flood crest discharges are shown by the hydrographs in Figure 2. In the vicinity of the neighboring border cities of Piedras Negras, Coahuila, and Eagle Pass, Texas, the river width at flood peak was estimated to exceed three miles.

The magnitude of this flood out of the semi-arid border region, so far inland, is remarkable. Perhaps only the Mississippi River among North American streams has ever passed a mightier single flood wave.

FALCON DAM SAVED LOWER VALLEY

Many lives were lost during this monstrous flood, especially in Mexico. Fortunately, the entire flood flow was stopped by the great Falcon Dam which spans the Rio Grande 270 river miles above its mouth on the Gulf. A total of 1,850,000 acre feet of water was captured behind that structure which providentially had its construction completed only ten months earlier! As a result, the populated, intensively cultivated international Lower Valley was spared the destruction of this great flood.

The occurrence of this flood and the success at Falcon Dam hastened efforts of the governments of the United States and Mexico to design and construct Amistad Dam just upstream of Del Rio, Texas, just as the two governments had collaborated on the design and construction of Falcon

Dam. This second great dam was completed in 1968 and today creates Lake Amistad, a huge body of water on the international boundary fed by the Pecos and Devils Rivers, as well as by the Rio Grande. The dam maintains a permanent lake of 3.5 million acre feet of stored water which is meted out for beneficial uses for both nations, and still provides an additional flood storage capacity of 1.75 million acre feet that spares downstream communities any flood trauma equivalent to Alice's 1954 flood. This 6.1-mile-long dam was constructed by the two governments under the 1944 Water Treaty, through their respective Sections of the International Boundary and Water Commission, for control of floods and to enable each country to conserve and utilize its allotted share of the waters of the river.

HURRICANE ALICE -- 1954

Hydrometeorological Report No. 55A (2) gives an interesting meteorological perspective to Hurricane Alice, an early season tropical storm that shall live long in the annals of copious rainfall events. What follows is taken directly from that report.

On June 24, 1954, a small hurricane in the western Gulf of Mexico, 300 miles southeast of Brownsville, was discovered by ship personnel. Hurricane Alice moved from its birthplace on a track toward the northwest, typical for this season and region. The storm crossed the coast some 50 miles south of the mouth of the Rio Grande at about noon on the 25th, and proceeded up from the short distance south of Brownsville to Laredo, and then to Del Rio, Texas. The surface wind at Brownsville rose to nearly 50 mph, while a pilot balloon measurement of wind speeds aloft showed a speed of 130 mph from the southeast at 3500 feet. As the center passed Del Rio at noon on the 26th, the highest surface wind was 33 mph (the fastest single mile of wind). The low-level jet winds also diminished. The highest speed revealed by the 8:00 AM pilot balloon observation was 48 mph at 3000 feet above sea level. However, the storm on this day still maintained its warm core as evidenced by the 500-mb temperature at Del Rio.

Continuing on its northwestward track, the storm crossed the Rio Grande to the region between the Big Bend of the Rio Grande and lower Pecos River. It stalled there during the night of the 26th and remained nearly stationary through the 27th. Early on the 28th, the storm remnants were barely discernible as a cyclonic wind circulation with a weak low pressure center. At this time it began to move across the lower Pecos River and finally lost its identity in North Texas. After it passed Del Rio, the cyclonic circulation of the storm was more distinct at 5000 feet than at the surface. This is typical of dissipating hurricanes. There were some weak indications in the 500-mb wind field that the storm interacted with a wave in the westerlies extending south from Montana as it was producing the record rainfall northwest of Del Rio.

During the progress of the storm over the relatively flat country of the Rio Grande Valley below Del Rio, rains were only moderate for a hurricane. In Texas there was a 6-inch center at Hebronville, about 130 miles northwest of Brownsville, Texas, and another center in excess of 6 inches near Uvalde, about 270 miles northwest of Brownsville. Stations along the Rio Grande experienced total precipitation ranging from a fraction of an inch to 4.5 inches. In Mexico, south of the storm track, precipitation was very light. Northwest of Del Rio, some orographic effect was apparent in the reported precipitation amounts. The storm encountered the steepest slopes of the narrowing valley of the Rio Grande between the Serranias del Burro in Mexico and the tip of the Balcones Escarpment in Texas. The first of the very heavy rains, near Langtry, Texas, however, began as the center of the dissipating hurricane arrived there. Detailed information on the wind flow is lacking, but it is reasonable to suppose that the prevailing flow into the area of heaviest rain was from the southeast.

Several hours after the passage of the hurricane center, the rain at Langtry slacked off and stopped altogether soon after noon on the 27th. The principal activity then shifted 30-60 miles north to the region between Pandale and Ozona, Texas. A succession of thunderstorm cells released very heavy rains along this axis for as long as the center of the transforming hurricane was located a short distance to the west of the axis. The precipitation ended over this region only after the storm center moved to the north. There are two rainfall centers shown on the isohyetal analysis at which the total accumulated precipitation for the storm, according to unofficial measurements, was 35 inches. The location of one (Everett) is in a saddle near the Pecos River at the head of a general slope up from the south, 1700 feet above sea level. The other is near a rim of a plateau at an elevation of 2200 feet.

The heavy rains are most closely related to the stalling of the northwestward movement of the hurricane remnant while it was transformed into a cold-core system when interacting with a weak wave in the westerlies. Although the overall precipitation pattern can be associated with the generally southward-facing slopes of the Edwards Plateau in the area northwest of Del Rio, specific isohyetal maxima and minima appear poorly correlated with places where the slopes are most pronounced.

ALICE -- AN HISTORICAL FOOTNOTE

Hurricane Alice was memorable to residents of the Rio Grande Valley, but the appellation also carries a curious footnote. In point of fact, there were two Hurricane Alices during calendar year 1954. The second Alice appeared December 30 as an uncommon winter-season storm 600 miles northeast of the Leeward Islands, and with its warm core, grew to hurricane force on New Year's Day 1955. According to Mr. Ralph Higgs (5), Meteorologist-in-Charge at the San Juan, Puerto Rico Weather Bureau Airport Station, people had difficulty accepting December Alice's existence.

> *This storm has aroused considerable interest. People were somewhat skeptical and slow in believing that a hurricane had actually formed. Already historians have expressed their opinion as to whether this was, or was not, the first of its kind in this area. In Puerto Rico a controversy centers about a storm that affected this island in the year 1816; one historian maintaining that it occurred in the month of January while another holds that it occurred in September. Reports from other islands mention a winter storm that affected the region many years ago. It appears that winter-time storms have been observed in these areas before. It is doubtful, however, whether any of them ever attained the intensity of "Alice" of 1955. It can be said of great certainty that this storm was definitely the first of its kind, at least, in the last 100 years.*

Unlike the flood from June's Alice, December's Alice brought beneficial winter rainfall to Puerto Rico, alleviating the normally dry November-March season on the Garden Isle.

It is likely the occurrence of two Alices in 1954 was instrumental in the Weather Bureau's decision to change names through the alphabet for the storms of each tropical season. Beginning with the next tropical storm in 1955, which occurred July 31 and was dubbed Tropical Storm Brenda, each year's list of tropical storm names was made different, a new policy commencing exactly at that time.

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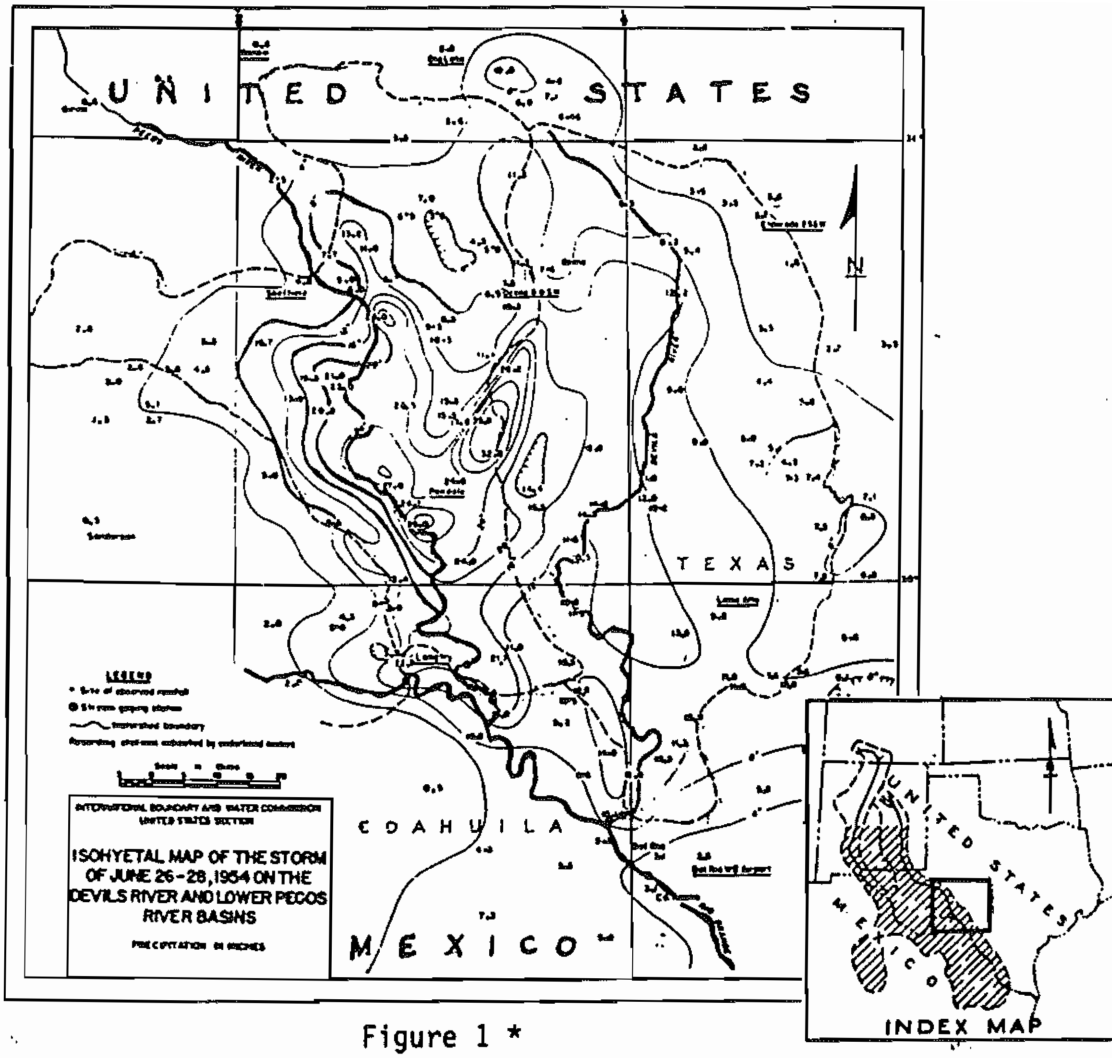

Figure 1 *

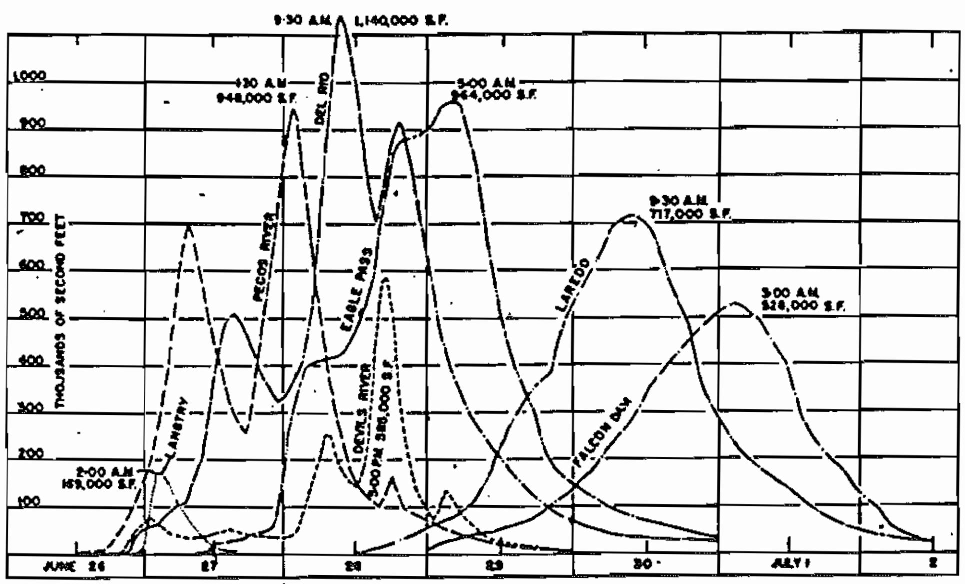

Figure 2 *

* Taken from: International Boundary and Water Commission, United States and Mexico - Water Bulletin No. 24, Flow of the Rio Grande and Related Data, 1954 (1).

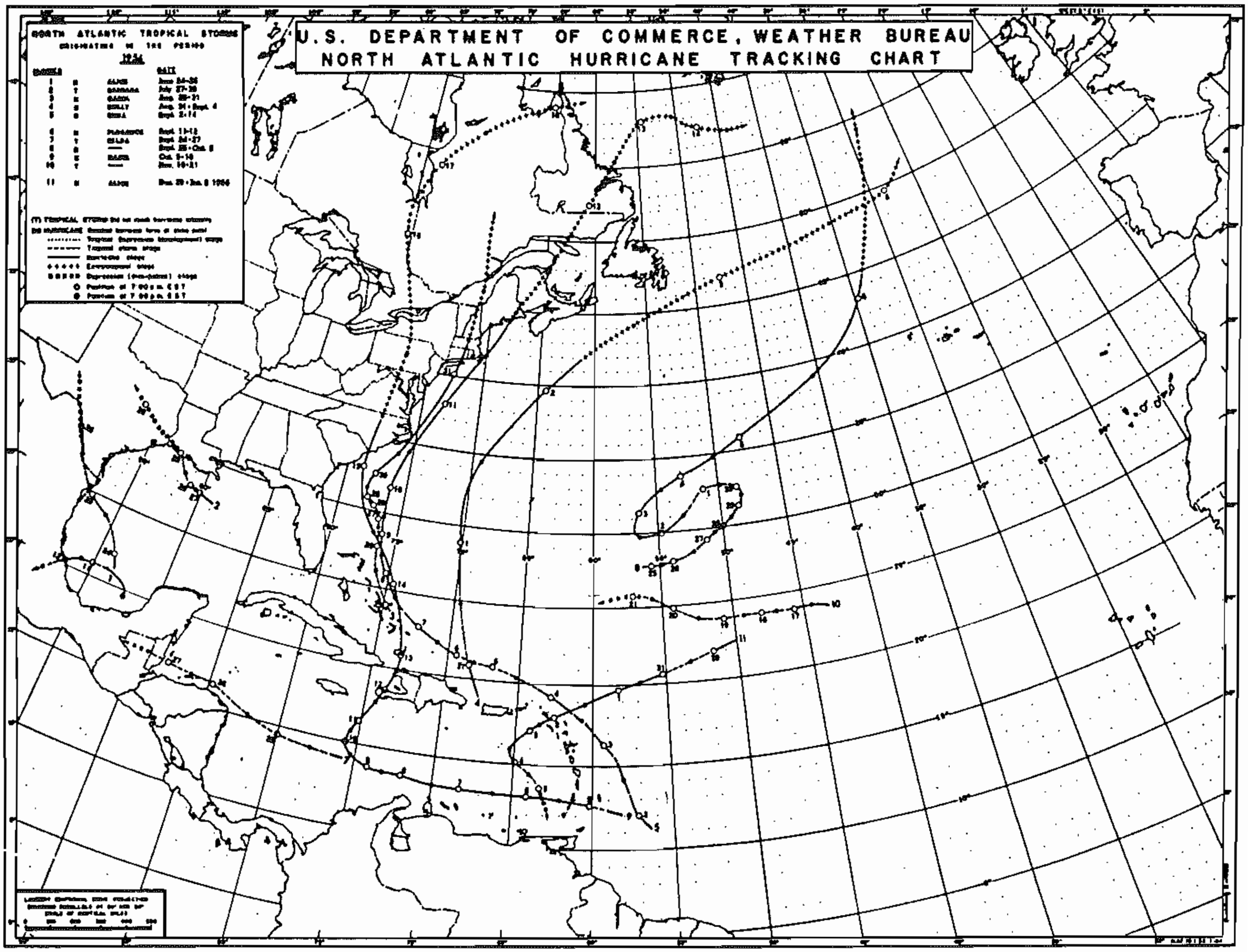
U.S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
NORTH ATLANTIC HURRICANE TRACKING CHART

Figure 3

THE AUGUST 1967 FLOODS OF EAST-CENTRAL ALASKA

East-Central Alaska (see Figure 1) has a continental climate with an average annual precipitation of about 12 inches. The area is shielded from the Gulf of Alaska, a rich source of moisture, by the Alaskan Range. During the rainy season from June through August, the monthly normal rainfall is from 1-1.5 inches with other months receiving less than one inch. Although heavy rainfall events are rare, a series of heavy rainfall events occurred in August 1967 when moisture from the remnants of Typhoon Hope interacted with an arctic front. As a result, east-central Alaska, including the city of Fairbanks, experienced record flooding.

From August 8-11, a low pressure from the remnants of Typhoon Hope was located in the Bering Sea. While most moisture bearing storms approach east-central Alaska from the west, this low was sending storms and moisture from the southwest. These upper level disturbances moved rapidly across east-central Alaska where the arctic front was located, and rainfall totals of over 2 inches were measured as a result of the frontal interaction. The rainfall peaked on August 12 when the low moved from the Bering Sea northeastward over the area. Rainfall totals of up to 4 inches were measured on August 12 in the Fairbanks area. Rainfall continued until August 17 with unofficial storm totals near 10 inches for the ten-day period. Figure 1 shows an isohyetal map of rainfall for August 1967, and the precipitation data are tabulated in Table 1.

The rainfall was the highest measured since records began in 1929, exceeding previous records by over 30 per cent. From August 8-15, Fairbanks Airport received 6.15 inches of rain, over half of the city's annual precipitation. In the White mountains northeast of the city in the headwaters of the Chena River, unofficial totals of over 10 inches were measured. The ensuing flooding resulted from a series of rainfall events, not a single event as is normal in the area.

Draining the area northeast of Fairbanks where the rainfall was heaviest, the Chena River experienced the worst flooding with numerous records broken. The Chena River gage located about 40 miles upstream of Fairbanks was completely destroyed on August 13. The Chena River at Eilson AFB above Fairbanks crested with a flow of 105,000 cubic feet per second (cfs) on August 14. As the flood wave moved downstream, the peak attenuated, and the Chena at Fairbanks crested with a flow of only 74,400 cfs on August 15. This flow in the Chena at Fairbanks was more than three times the the previous record discharge of 24,200 cfs in May 1948. Flood waters inundated over 95 per cent of the city and were over 5 feet deep in places. Over 12,000 persons were evacuated from their homes, and six persons died. Further downstream on the Tanana River, 300 residents of Nenana were forced to evacuate when flood waters in town were over 6 feet deep. The peak discharge of 122,000 cfs at Nenana eclipsed the previous record. Record and near record flooding occurred in uninhabited areas including the Salcha, Nenana, Chatanika, and Tolovana Rivers. Total damages were $85 million.

Largely because of a lack of data, little advance warning for such a severe flood was provided. To aid the warning process in the future, the Weather Bureau, Corps of Engineers, and U.S. Geological Survey combined to design and install a flood warning system to protect Fairbanks.

Before the 1968 flood season, six river gaging sites were installed to provide advanced warning to the community. Numerous studies were undertaken by the State of Alaska and the USGS to define flood frequencies in the area.

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No. (fig. 1)	U.S. Weather Bureau station	Monthly total
1	Bettles FAA Airport	2.17
2	Big Delta FAA	1.56
3	Canyon Village	1.72
4	Central No. 2	5.70
5	Chalkyitsik	1.37
6	Chena Hot Springs	7.74
7	Circle Hot Springs	5.75
8	Clear Airport	10.06
9	Clearwater	2.37
10	College Mag Obsy	7.36
11	Delta Junction	2.48
12	Eielson	7.47
13	Fairbanks WB Airport	6.20
14	Fort Yukon	.35
15	Galena	4.70
16	Gilmore Creek	9.49
17	Indian Mountain	3.44
18	Manley Hot Springs	6.89
19	McGarth WB Airport	3.41
20	McKinley Park	3.45
21	Nenana FAA	8.26
22	Northway FAA AP	1.85
23	Rampart No. 2	6.08
24	Richardson	2.87
25	Summit FAA	3.52
26	Tanana FAA	5.06
27	The Gracious House	7.54
28	Trims Camp	9.16
29	University Exp. Sta	6.57
30	West Fork	4.52
31	Wild Lake No. 2	2.00
32	Wonder Lake	3.81

Table 1. Precipitation, in inches, during August 1967 in east-central Alaska

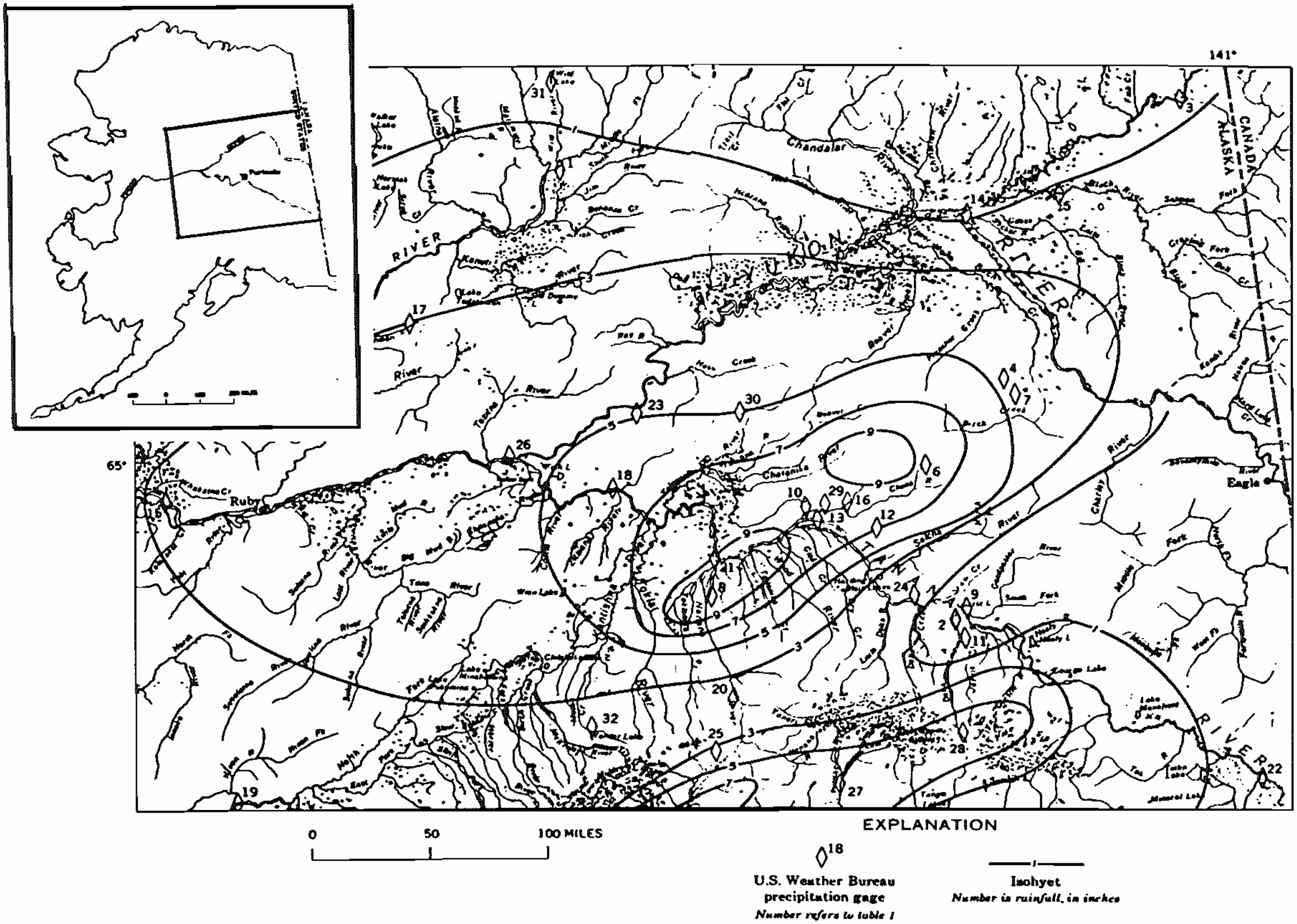

Figure 1

Total Rainfall for August 1967 in East-Central Alaska

FLOODING FROM HURRICANE AGNES
JUNE 15-23, 1972

Hurricane Agnes was one of the costliest disasters in U.S. history. As Agnes moved up the Atlantic seaboard, her copious rains produced record flooding from the Carolinas to upstate New York.

The hurricane was born as a depression off the coast of the Yucatan Peninsula on June 15, 1972, and strengthened into a minimum hurricane as it moved northward as shown in Figure 1. Agnes had a poorly defined eye, a minimum surface pressure of only 978 mb and peak winds of only 85 mph. With wind gusts of only 55 miles per hour and tides 6-7 feet above normal, Agnes made landfall the afternoon of June 19 on the Florida Panhandle. After travelling northeastward through Georgia and the Carolinas, Agnes restrengthened over the Atlantic. On August 23, Agnes made landfall in New Jersey and went extratropical over New York and Pennsylvania.

Agnes brought up to 16 inches of rain on the western half of the island of Cuba, a portent of rainfall to come. Alabama, Georgia, Florida, and eastern portions of the Carolinas received 4 to 8 inches of rainfall, a welcome relief from the droughty conditions there. Agnes dumped 4-10 inches of rainfall with isolated 13-inch amounts along the eastern slopes of the Appalachian chain from the Carolinas northward to upstate New York. On August 21 and 22, parts of Maryland received over 11 inches in 24 hours, nearing 24-hour rainfall records in the state. Central Pennsylvania received storm total rainfall from 8 to 12 inches, with some areas receiving up to 18 inches.

Record or near record flooding occurred from the Carolinas to New York. Major river flooding followed flash flooding in the western parts of North and South Carolina. The James River flooded over 200 blocks of downtown Richmond. Its crest stage exceeded the previous record set in 1771 by over 6 feet. The flood on the Appamattox River at Farmersville, Virginia, was described as the most destructive in history. Major flooding also occurred in the Potomac River Basin, while small rivers in upstate New York reached record levels.

Pennsylvania experienced some of the worst flooding when almost all navigable streams in the western portion of the state were in flood, and numerous records were broken in the eastern part of the state. Flood levels in the Susquehanna exceeded records set during the flooding of 1936 by 3-6 feet. In Harrisburg, flood waters were in the first floor of the Governor's Mansion. The Schuylkill River in southeastern Pennsylvania exceeded previous levels by 8-10 feet. The Allegheny River in New York and Pennsylvania exceeded record levels. The Youghiogheny and Monongohela experienced major flooding. Flood waters from these two rivers merged with the Allegheny to produce the highest crest on the Ohio River at Pittsburgh since 1942.

In total, over 40 record river stages were eclipsed and countless others approached. Many records which were broken had been set during the great flood of 1936. (The great flood of 1936 broke some records dating back to the 1700s.) Many records not eclipsed had been set during

Camille in 1969 and the hurricane twins of 1955, Connie and Diane. No other single United States storm has produced flooding of such magnitude over as wide an area as Agnes.

Agnes caused $3.47 billion in damages, the most costly U.S. hurricane ever at the time. Over 100,000 dwellings were damaged or destroyed, and over 120,000 families suffered property losses. There were 122 deaths in the United States and seven in Cuba. The entire state of Pennsylvania was declared a disaster area after suffering damages of $2.31 billion.

Minimum strength hurricanes such as Agnes can produce extremely heavy rainfall and disastrous flooding over a large area and can be beneficial in breaking droughts as Agnes did in Georgia, Florida, and parts of the Carolinas. However, the damage due to flooding can easily exceed those from winds and tornadoes associated with these hurricanes, and hurricane Agnes was such a storm. The areal extent and severity of its flooding remains a standard by which to compare future flood events.

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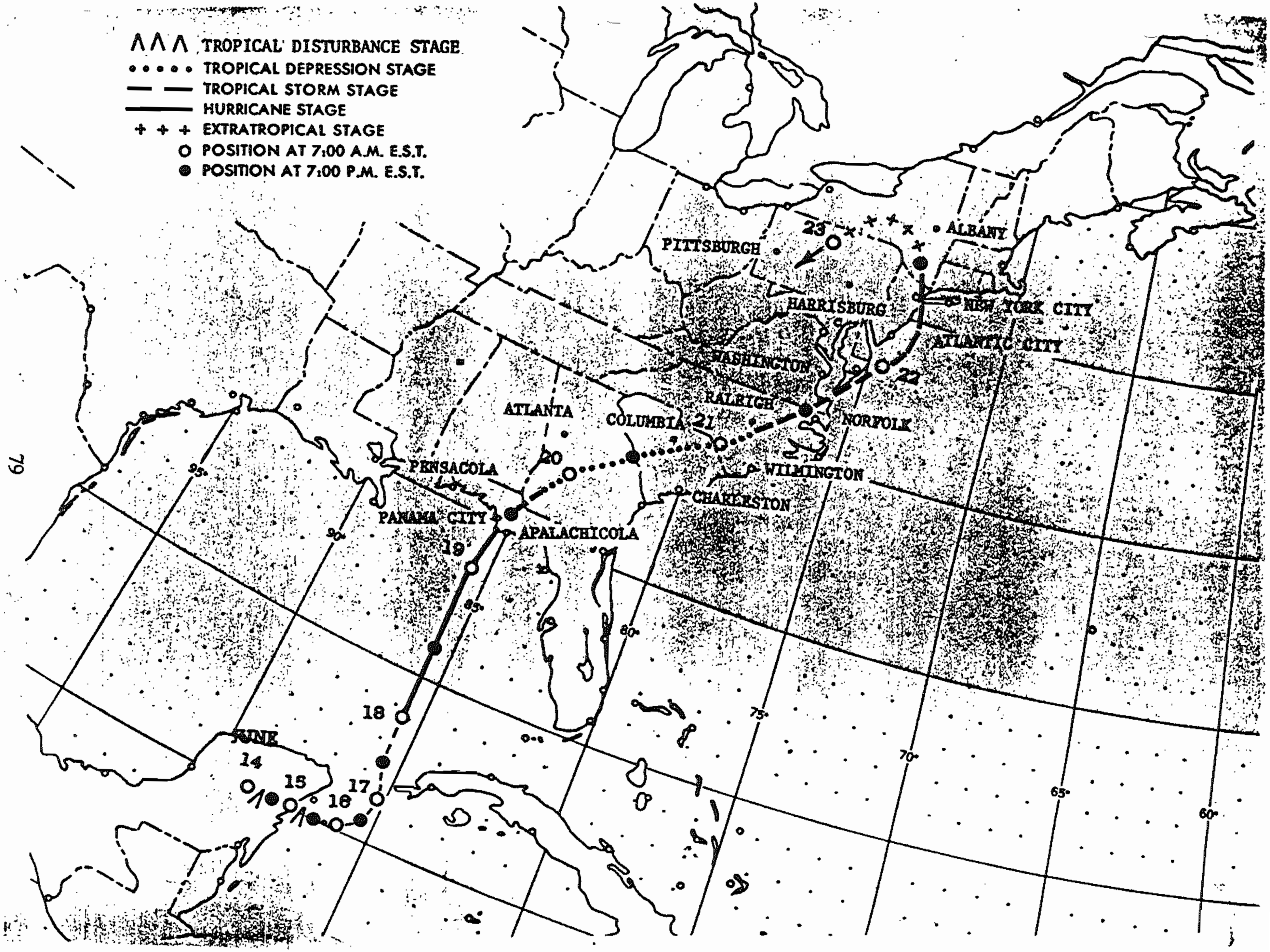

Figure 1. Agnes's Track

THE BIG THOMPSON FLASH FLOOD
JULY 31 - AUGUST 1, 1976

During the evening of July 31 and the morning of August 1, 1976, a devastating flash flood occurred in the Big Thompson River basin in north-central Colorado. The Big Thompson River flows through scenic Big Thompson Canyon. This popular tourist attraction was jammed with 3500 tourists preparing to celebrate Colorado's 100th anniversary the following day. After 12 inches of rain fell, the ensuing flash flood claimed 139 lives and caused over $35 million in damages.

The Big Thompson River has headwaters at the Continental Divide at about an 11,000-foot elevation. The basin contains soils that are gravelly and stony on the ridges to sandy near the streambeds. The streambed has steep slopes, and the river drains into the South Platte River at an elevation of about 4700 feet. Because of the steep slopes and little topsoil, the Big Thompson River and Canyon are susceptible to damaging flash floods.

On July 31, air in the Central Plains and intermountain area was abnormally moist and conditionally unstable. During the previous two days, a front had been slowly moving southward through the Great Plains. By 5:30 PM on July 31, the front had become almost stationary in an east-west line through Missouri, Kansas, and Colorado, and then trailed northward in the foothills of the Rockies. By 6:30 PM, strong thunderstorms had developed in a north-south line in the foothills, producing rains with radar intensities of VIP 3 and VIP 4. East and southeasterly winds provided moisture to the storms. During the next four-and-a-half hours, the Big Thompson basin received up to 12 inches of rain. Figure 1 shows the total rainfall in Big Thompson Canyon for July 31 - August 2, 1976.

As night fell, disastrous flash flooding occurred in the lower portion of Big Thompson Canyon and River drainage. In the Big Thompson Canyon, the flood peak moved at a rate of almost eight miles per hour and reached the mouth of Big Thompson Canyon at 9:40 PM, near the end of the heavy rainfall. The peak discharge at the Big Thompson River near Drake, located at the mouth of the Canyon, was 31,220 cfs as shown in Figure 2. This peak flow was four times the previous record and 1.8 times the estimated 100-year flood flow. The peak stage of 19.7 feet exceeded the previous record by more than ten feet. The gage was destroyed during the flood, and all readings were based on observers and on high water marks. After exiting Big Thompson Canyon, the river bed widens rapidly; and the peak flow attenuated quickly.

Heavy rains fell in the Cache la Poudre Basin immediately to the north of the Big Thompson Basin. Flooding was severe, but fortunately the area was only sparsely populated. Damages were not as severe as in the Big Thompson Canyon area.

Flood damages totaled $35.5 million, and 139 people were killed. Five persons are still unaccounted for. The flood destroyed 316 homes, 45 mobile homes, and 52 businesses. Where dirt roads existed previously, steep-sided gullies 600 feet long, 20 feet wide, and 7 feet deep were made by the flood waters. The U.S. Army Corps of Engineers contracted to remove 197 automobiles and over 300,000 cubic yards of debris, part of which was houses. Much of Highway 34, a scenic drive through Big Thompson Canyon, was washed away.

While the rainfall was very heavy and occurred over an unusually large area, rainfall of this magnitude is not unprecedented in the foothills of Colorado. Storms in May 1935 and June 1965 produced heavier rainfall totals with record flooding occurring.

The flash flood in Big Thompson Canyon will be remembered for its destruction. This event prompted many changes in warnings and preparedness for flash flooding in the foothills area in Colorado. It also heightened awareness of flash floods within the National Weather Service.

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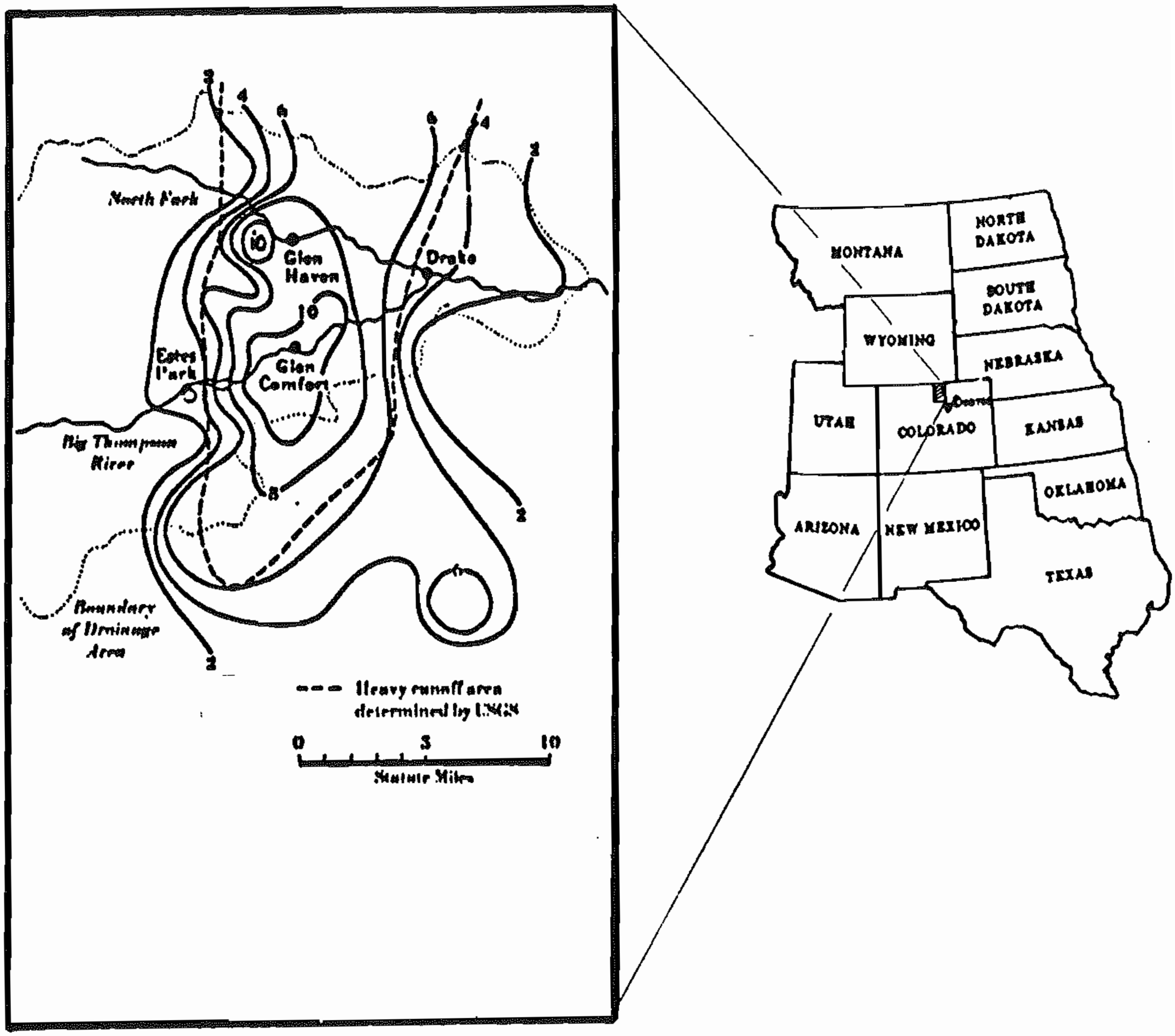

Figure 1

Precipitation (in inches) July 31-August 2, 1976
(From NOAA, 1976, p. 3, and Revisions of April 1977)

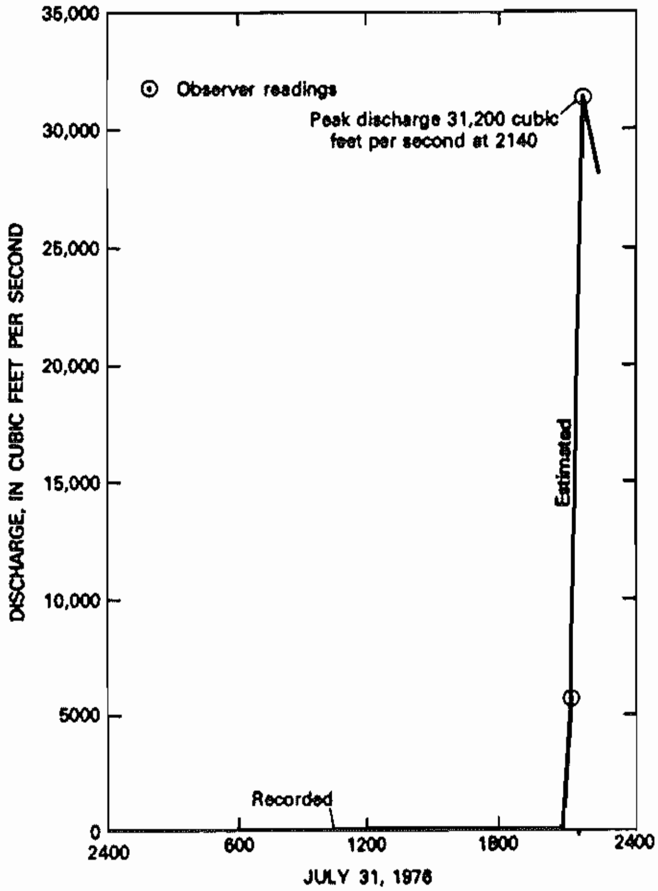

Figure 2

Discharge hydrograph for rising stage at the Big Thompson River at mouth of canyon, near Drake (Site 23)

FLOODING IN WEST-CENTRAL NEW MEXICO AND ARIZONA, DECEMBER 17-20, 1978

From November 1978 to March 1979, abnormally heavy rainfall produced disastrous and record flooding in Arizona and west-central New Mexico in the area shown in Figure 1.

During the fall and early winter of 1978, a series of upper level lows developed off the southwest coast of California and the western coast of Mexico's Baja California. As these lows moved northwestward, unusually heavy rainfall would occur in Arizona and New Mexico. There were five distinct periods of heavy rainfall on November 10-12 and 23-26, December 17-20, January 17-18, and March 28-31. From November 1978 to March 1979, several stations in central and eastern Arizona and western New Mexico received 35-40 inches of rainfall, nearly 20 inches above the normal for the period. An additional 20 stations received more than 10 inches above their normal for the period. Precipitation fell partly as rain and partly as snow, with alternating periods of snowfall and snowmelt occurring. During these storms, rainfall was of only moderate intensity but fell almost continuously. This differs from most flood producing rainfall events in the area which are usually of short duration and high intensity. Serious flooding occurred after each period, but the most serious and widespread occurred after the rains of December 17-20.

From November 10-12, north-central Arizona received 2-7 inches of rain, with Crown King Station in central Arizona receiving 8.55 inches. From November 23-26, 1-5 inches of rain fell in eastern Arizona and western New Mexico, with areas near Tucson measuring over 5 inches of rain. The higher elevations received snow. The flows in the upper portions of the San Francisco River basin reached their highest levels since records began. The heaviest precipitation was in the headwaters, and the flood wave attenuated quickly as it moved downstream. Overall, the recurrence interval for the flood levels was estimated to be 10-25 years.

While the early part of December had turned cold, warmer temperatures the middle of December melted most of the snowpack. Only about 10 per cent of the area had snow cover by December 17, and the soils in the Gila and Salt River basins were saturated. From December 17-20, rainfall totalling 3-10 inches fell in the area. As a result of these rains, the Little Colorado River at Winslow, Arizona, reached its highest level since 1952. The flow in Chevelon Creek, which drains into the Little Colorado above Winslow, was the highest since 1929. In Winslow, seventeen hundred people were evacuated from their homes, and in some subdivisions, water was five feet deep. Only minor flooding was occurred in the remainder of the Little Colorado River.

The Gila River basin was hardest hit during the storm period of December 17-20. The flood frequency of the Gila above its confluence with the San Francisco River was estimated at over 100 years. In the headwaters of the Gila River, the Gila Hot Springs Bath House, built in the 1880s, had never flooded but had flood water in it two feet deep. The flood wave then passed the gaging site at Gila, New Mexico. Quickly, the flood crest moved downstream and grew as shown in Figure 2. In the Gila Middle Box Canyon between Gila and Redrock, New Mexico, flood debris was found 150 feet above the river channel. The Gila at Redrock recorded its highest stage in over 90 years. Further downstream at Duncan, Arizona, waters from the Gila

River were over 7 feet deep in parts of town, and 75 homes were destroyed. At the same time, minor flooding was occurring in the headwaters of the San Francisco River. When all tributary flows combined with local runoff downstream, the flood levels on the lower reaches of the San Francisco River were the second highest of this century, exceeded only by the floods of 1972. Near Clifton, Arizona, flood waters from the San Francisco River and the Gila River combined to produce a peak flow of over 100,000 cfs in the Gila River. Downstream, the floodwaters inundated much of the Safford Valley, and major damage to agricultural interests occurred. San Carlos Reservoir, formed by Coolidge Dam, was able to hold all the flood waters from this storm event, and only moderate flooding occurred from Coolidge Dam downstream to the Gila's confluence with the Salt River.

On December 18 in the Salt River basin, record peaks occurred on the Black and White Rivers and Bonita Creek. Since only 25 years of records were available, these peak flows may not have been the highest this century. Stewart Mountain Dam on the Salt River and Bartlett Dam on the Verde River captured much of the flood waters, but had to make flood releases on December 18 and 19. Reservoir outflows combined with local runoff in Phoenix produced the fourth highest flood crest at Phoenix since 1891. Outflows from Waddell Dam on the Agua Fria added to the flood crest in the Salt and Gila Rivers below Phoenix.

The storms of January 17-18 and March 28-31 added to the above normal rainfall in the area but did not produce any major flooding.

Damage totalled over $150 million; the majority of this was agricultural. Twelve deaths were recorded. Ten counties in Arizona and three counties in New Mexico were declared a disaster area.

There are 8 reservoirs in the Gila and Salt River basins built primarily for water conservation purposes with a total storage capacity of over 3.3 million acre-feet. In early December, 1.6 million acre-feet of this storage was available. On the Gila River, San Carlos Reservoir with a capacity of 1.07 million acre-feet was able to contain the 100,000 cfs flood peak. Because of the extended period of rain and the spring snowmelt, water began to flow over the emergency spillway on April 22, the first occurrence since water was impounded in 1929. In the Salt River basin, the peak flow at Phoenix without reservoirs was projected to have been as much as 224,000 cfs. The reservoirs were able to reduce the peak flow to only 126,000 cfs. Damages would have been much worse if the reservoirs had not served to reduce the peak flows in the Gila and Salt River basins.

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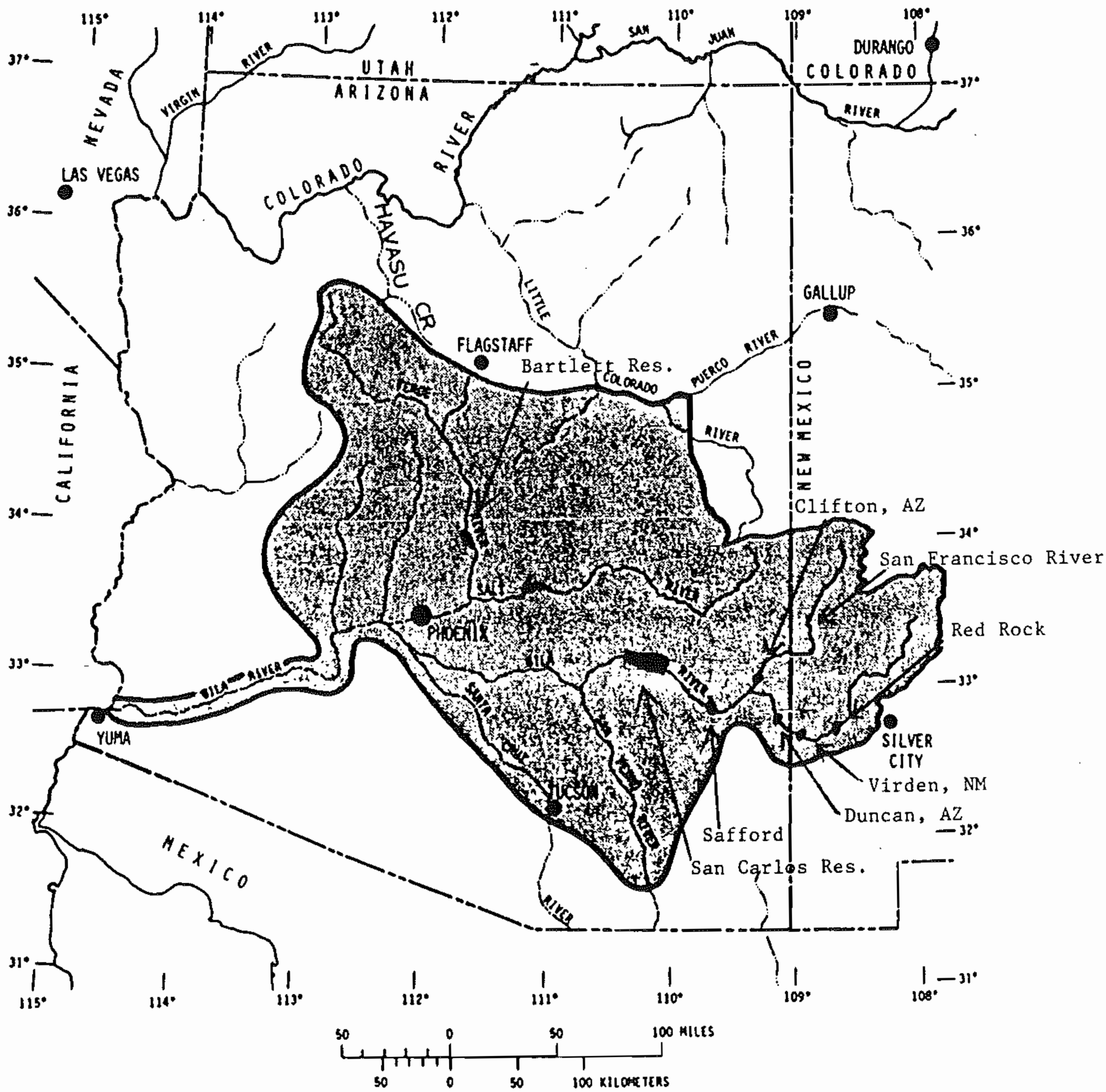

Figure 1. Area of most severe flooding November 1978 - March 1979

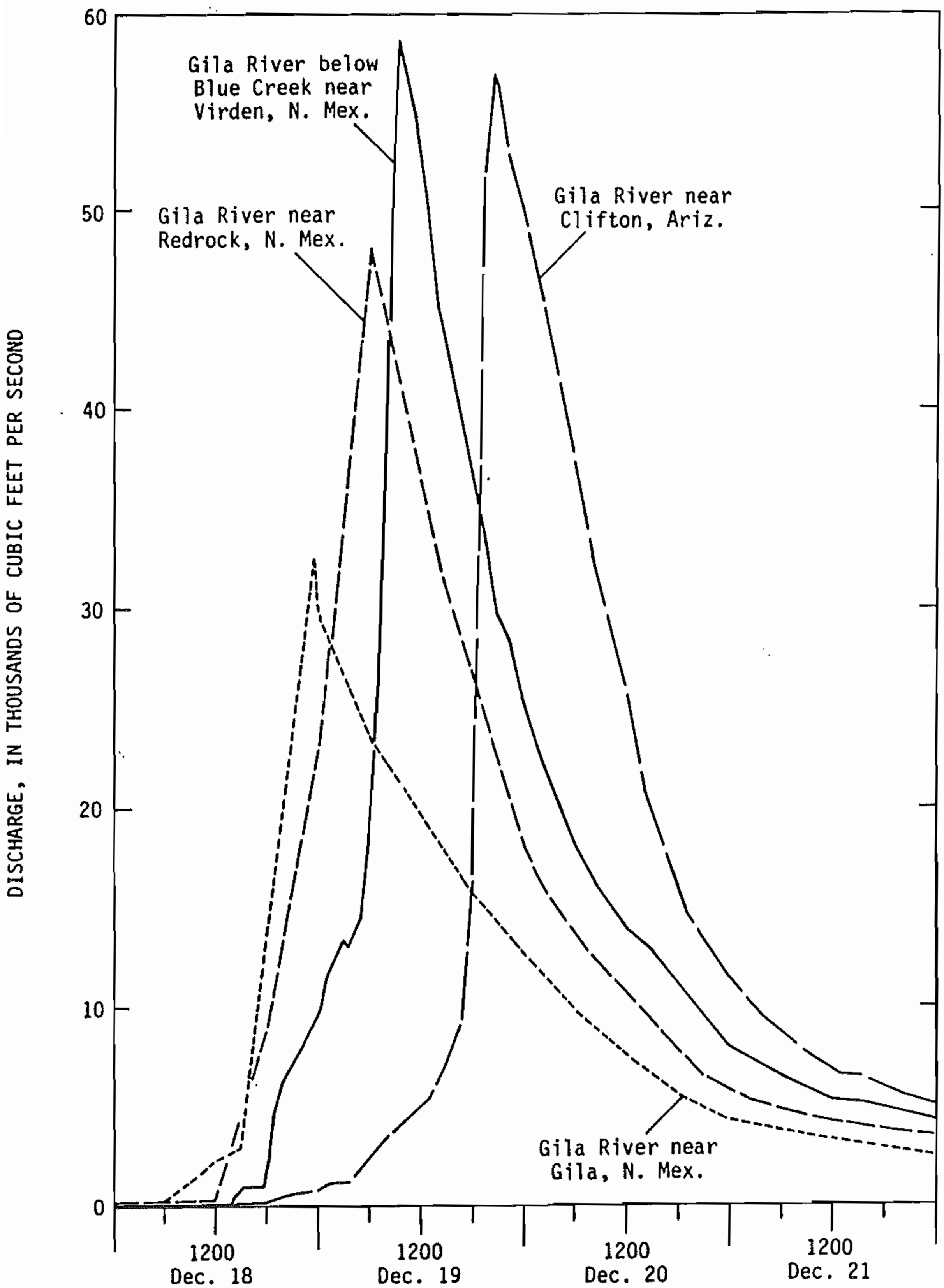

Figure 2. Hydrograph as flood wave moves down Gila River.

APPENDIX -- FLOOD SUMMAARY

River	Date	Gage	Maximum Discharge CFS	Drainage Area Sq.Miles	Deaths
Canadian	Sep. 1904	Logan, NM	278,000	11,141	Unknown,dozens
Sacramento	Mar. 1907	Sacramento, CA	559,000	25,451	Unknown, few
Savannah	Aug. 1908	Augusta, GA	307,000	7,232	Unknown, few
Rio Grande	Oct. 1911	Del Norte, CO	18,000	1,320	Unknown, few
Miami	Mar. 1913	Dayton, OH	250,000	2,525	More than 400
Mississippi	Apr.-May 1927	Arkansas City,AR	2,662,000	1,104,360	246
Ohio	Mar. 1936	Pittsburgh, PA	795,000	18,200	107
Ohio	Jan. 1937	Cincinnati, OH Louisville, KY Paducah, KY	950,000 1,100,000 1,980,000	76,580 91,170 202,713	Unknown, dozens
Kansas, Missouri	Jul. 1951	Kansas City, MO	573,000	489,162	28
Missouri	Apr. 1952	Bismarck, ND	500,000	186,360	11
Rio Grande	Jun. 1954	Del Rio, TX Eagle Pass, TX Laredo, TX	1,140,000 964,000 717,000	126,940 130,575 138,743	55
Chena	Aug. 1967	Fairbanks, AK	74,400	1,980	6
Susquehana	Jun. 1972	Harrisburg, PA	1,020,000	24,100	122
Big Thompson	Jul. 1976	Drake, CO	31,220	305	139
Arizona Floods	Dec. 1978	Phoenix, AZ	126,000	13,225	12

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